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Journal

—OF THE—

American Ceramic Society

A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries.

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Organized at the Pittsburgh meeting, Feb. 3–5, 1919.

Division.	*Chairman.*
Enamels	J. W. Sanders.
Terra Cotta	F. B. Ortman.
White Ware and Porcelain	C. L. Sebring.
Refractories	A. V. Bleininger.
Glass	C. H. Kerr.
Brick and Tile	M. W. Blair.
Wall and Floor Tile	F. W. Walker, Sr.

JOURNAL
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Vol. 2 **February, 1919** **No. 2**

EDITORIALS.

THE CONVENTION.

The twenty-first annual meeting of the American Ceramic Society, Pittsburgh, Pa., adjourned *sine die* at six o'clock on the evening of the sixth of February, and it was a wonderful and genuine success. There had been anxious thoughts in official circles as the time drew near for the meeting. The year had been full of activities, but some of the developments were still in the experimental stage. There had been a large influx of members but the fear of undue dilution which had existed in the old days had not been entirely banished. Could the spirit of the Society be kept as keenly alive among a thousand men as it had been among two or three hundred? Would the passion for research not be reduced in intensity by being spread too thin? These and other questions had yet to be answered.

At the Fort Pitt Hotel on Sunday afternoon the answers began to come. The well-known faces showed themselves, keen, alert, and friendly as before. The atmosphere grew warmer and more pleasant as the hours passed until all doubts vanished and unknown quantities produced their own solution.

The Board of Trustees met on Sunday evening and remained in session until the early hours of Monday morning. It was then decided that all actions of the Board should be published from time to time in the Journal, so that it is not necessary to detail them here. Let it suffice to say that the Board is unanimous in the continuance of a broad policy of development and advance without sacrificing the principles of unity and altruism for which the Society has always stood.

The business meeting on Monday was held in the Assembly Room and although this room was capable of seating a hundred and fifty persons, it was almost inconveniently crowded. The Secretary had provided about 250 badges, which in ordinary times would have been more than enough, but even on the first day the stock ran low and before noon on the second day it was entirely exhausted.

The meeting was called to order at 10 A.M. by President Staley, who delivered the annual address in which several important suggestions were offered relative to the future activities of the Society. The address was referred to a committee of three, who duly considered the points raised and referred them to the proper committees.

The routine business was then disposed of in the usual way. The report of the Board of Trustees was read and the finances were shown to be in a flourishing condition. Five thousand dollars had been invested in Government securities and there was a cash balance of eighteen hundred dollars. The membership roll contained 1036 names and more were being added as fast as the necessary action could be taken.

The reports of committees consumed some time and a few of these were postponed to the final business session. Mr. A. F. Greaves-Walker, Chairman of the War Service Committee, told of the ways in which members of the Society had been able to assist the country to overcome the difficulties occasioned by war conditions. Dr. E. W. Washburn reported that the National Research Council was to be reconstituted on a peace basis and said that the Society was invited to nominate one of its members to the Council. Mr. Purdy, speaking for the Membership Committee, announced that their goal was 2,000 members by the end of the year. Mr. Beecher, Chairman of the Committee on Standards, gave a résumé of their report and stated that the full report would be printed and issued to the members for criticism or confirmation. The Committee on Rules was charged with the duty of considering several suggested changes which were to be reported to the Society before final adjournment so that action might be taken by ballot.

The formation of Professional Divisions was discussed and the opinion was generally expressed that these might be expected to constitute a source of great strength to the work of the Society.

Dr. E. W. Washburn asked that a committee be appointed to define the meaning of the term "ceramic" and to take steps to place a definition, accepted by the Society, before the publishers of dictionaries and encyclopedias.

An adjournment for luncheon was taken at one o'clock and soon after two o'clock the second session was called to order.

The reading of papers now began, the first group being of contributions relating to refractories and especially to graphite crucibles. These papers will be printed in full in due course and it will suffice to say that the subjects were treated with technical thoroughness.

Monday evening was set apart for the organization of Professional Divisions. The Society met as a whole in the Assembly Room at eight o'clock and Mr. Purdy spoke of the importance of the work which the Divisions might be expected to accomplish. After some discussion as to methods of procedure, the members separated into groups for the purpose of organization. Divisions were suggested on enamels, glass refractories, abrasives, porcelain, brick and tile, stoneware, terra cotta and faience, wall and floor tile, and white wares. Not all of these were formed at once, but steps were taken which led or will lead to complete organization. Each Division is to have its own officers. A general supervision is to be exercised by the Board of Trustees but, having regard only to the rules governing the Society in general, Divisions will be expected to work out their own plans.

Late in the evening the Board of Trustees held a meeting at which the qualifications of a number of associates nominated for elevation to membership were reviewed.

On Tuesday morning the session met in the banquet hall. By request of the Division of Enamels, the papers relating to this subject were called first and following these were the papers on glass and glass pots. At two o'clock a joint session was held with the United States Potters Association, of which a large delegation was in attendance from East Liverpool and the neighbor-

ing pottery centers. On this occasion there were probably four hundred persons present, thus making the meeting by far the largest ever held by the Society. Papers on white ware manufacture were read and discussed, and when the closing hour arrived the pottery men adjourned to the Assembly Room, where the White Ware Division was organized with Mr. C. L. Sebring as chairman. At the same time the Division on Glass met in a committee room and discussed the special problems of their subject.

The dinner on Tuesday evening was a notable event. The Society has not as a rule been favorable to the banquet idea. This was the twentieth anniversary, however, and the occasion seemed to call for a celebration. An attempt was made to secure H. A. Wheeler, the first president, as chairman, but he was in far-off Texas and could not be reached. The Board of Trustees, therefore, delegated Professor C. F. Binns, the senior president present, to take the chair. Notwithstanding the loss of the menus and song books, the pianist rose to the occasion and with due assistance from Messrs. Purdy and Forester the songs were rendered. The toast list was arranged in two groups of three subjects each: "What We Are," "What We Were," and "What We Will Be," by President Staley, Professor Bleininger and Dr. Tillotson, respectively, and "Scientifically Speaking," "Practically Speaking," and "Periodically Speaking," by Dr. Washburn, Mr. E. W. Wells and Mr. L. E. Barringer. Mr. Wells kindly consented to speak at a few minutes' notice as the expected speaker was not present.

Two hundred and seventeen persons were present, including a small number of ladies. Perhaps if this becomes an annual event the fair sex may be more numerously represented.

On Wednesday morning the Society was compelled to return to the Assembly Room, the larger room being otherwise occupied. The result was a rather crowded condition but everyone made the best of it. The reading of papers was continued and the end of the program was reached by four o'clock in the afternoon. The vice-president then took the chair and the adjourned business meeting was resumed. Several reports which had been postponed were read. The chairman announced that Mr. Samuel

Geijsbeek, the man who had 21 years before suggested the formation of the Society, was in the room and was requested to show himself. Mr. Geijsbeek accordingly came to the table and was received with an ovation.

The result of the annual election was then announced: R. T. Stull, President; R. H. Minton, Vice-President; C. F. Binns, Secretary; R. K. Hursh, Treasurer; and M. F. Beecher, Trustee. These gentlemen were then duly installed and the meeting stood adjourned.

The outstanding characteristics of the Convention were the spirit of progress and genuine interest in the future of the Society.

CONVENTION TRIPS.

Thursday, February 6th, was devoted to excursions to places of special interest to members of the Society. One party set out to visit the glass plants at Rochester and Sharpsburgh. A second party visited the Bureau of Standards, the Bureau of Mines, and Mellon Institute. A third party proceeded to the plant of the Harbison-Walker Refractories Company.

At the Bureau of Standards the history of the Arsenal, built in 1814, was related and the modern laboratories were inspected. The recently erected plant for the manufacture of optical glass proved of great interest as did also the processes of the manufacture of the pots of fire clay and porcelain. The giant testing machines and the freezing tests of structural materials were explained.

After lunching in East Liberty, the party went to the extensive laboratories of the Bureau of Mines, where inspection was made of the Government equipment for investigation and research. A test of gas masks under actual mine conditions proved of great interest; Messrs. D. A. Lyons and R. T. Stull guided the party through the Bureau. At Mellon Institute Dr. E. W. Tillotson explained the work which was being done and an inspection of the laboratories followed.

At the plant of the Harbison-Walker Refractories Company, Mr. Town, the chemist in charge, conducted the visitors through the laboratory and exhibited the special furnaces used for attaining extremely high temperatures. The manufacture of silica brick was new to many and very interesting. The remarkable effect of a small percentage of lime on the crushed rock was noted, as was also the fact that in burning the brick a large allowance had to be made for expansion. It was also noted that on account of underground moisture, the waste heat was carried to the driers by overhead ducts. Many thanks are due to the staff of the Harbison-Walker Company for the hospitality shown to the visitors.

In the afternoon a group of members proceeded to Sharpsburg on the Allegheny River and there visited the bottle factory of the H. J. Heinz Company. Mr. Ripley, of this company, conducted the party through the plant. The Owens bottle machines and glass melting furnaces used in connection therewith proved of great interest.

The trips, although informally arranged, proved thoroughly enjoyable and profitable. It is to be hoped that at the future conventions particular attention will be given to this phase of the meeting. It is true that the Summer meetings are devoted for the most part to inspection and sight-seeing trips, but as our annual meetings are held in different parts of the country each year every opportunity should be given to those in attendance to visit the ceramic plants of interest in the vicinity of the meeting place.

ORIGINAL PAPERS AND DISCUSSIONS.

REFRACTORIES FOR THE ZINC INDUSTRY.

By M. Grover Babcock.

Introduction.

One special branch of the ceramic industry which has not been discussed in the publications of the American Ceramic Society is the subject of zinc refractories, which consists principally of the manufacture of retort and condenser shapes as the finished products and plastic fire clays, grog and coke as the raw materials. The bond clays, however, are by far the most important part of the retort batch and are of interest to the clay worker. It would seem desirable, therefore, to bring to the attention of the Society a résumé of the requirements of retorts; the materials of a retort batch; their chemical and physical properties; tests of refractory bond clays used in retorts; preparation and the proportions of the materials used for the batch; treatment of the batch; manufacture of the product; and the life of the retort and condenser.

The principal shapes under the general term zinc refractories are, in the order of their importance, retorts (spelter vessels), condensers (spelter catchers), and high-grade fire brick. The first two are least familiar to most ceramists. Retorts are usually either cylindrical or elliptical in shape, 48″–51″ long, 8″ in diameter, inside, and 1″ thick, weighing about 134 pounds when burned. The condensers are $14'' \times 5^1/_2'' \times 2^1/_4''$, inside measurements, and are leg-shape or conical in form, being bulged out near one end, with a belly to collect the spelter.

The requirements of clay retorts used in the distillation of zinc ores are very exacting and may be summarized as follows:

First: They must possess the property of sufficient refractoriness to withstand the high heat of the melting furnace and to maintain a maximum heat conductivity to support the endothermic reaction of the ore during the reduction.

Second: A great plasticity of the bonding clay is desired, to cement together the grains of calcined grog, or chamotte, into a compact mass.

Third: Retorts must possess considerable mechanical strength and toughness, especially in the dry state, as they are subjected to several handlings before being placed in the furnaces. Strength is also necessary to maintain the shape while under load of ore and coke at smelting temperatures, 1300–1400° C.

Fourth: They should become dense at 1300–1400° C or lower, thereby producing a structure with a minimum porosity, which makes them impervious to the zinc vapors at these temperatures and chemically inert to the corroding action of the various slags produced by impurities in the gangue of the zinc ores.

Fifth: The retorts must be made with thin walls to obtain the maximum conductivity necessary for the endothermic reaction taking place inside the retort and at the same time maintain the heat flow necessary for the continuation of that reaction without a drop in temperature.

Sixth: The properties of retaining a sound structure after molding and of drying free from incipient cracks, and of burning to a dense product, are especially essential to a good retort.

These requirements are dependent primarily on the raw materials used. Of the raw materials, the bond clays are of primary importance and the grog secondary. Unfortunately, the ideal bond clay for this type of refractory has never been discovered. The clays which have been found most satisfactory by years of practical experience are those from the Cheltenham district in Missouri and those from the Woodbridge district in New Jersey. These clays possess the properties demanded to a certain degree and are comparatively cheap, but there is still room for improvement. If the perfect materials for retorts are discovered, the zinc industry will not be slow in making use of them.

In considering a clay for zinc refractories, a few general chemical properties which are important can be enumerated. It should be low in ferric oxide, lime and alkalies, which tend to increase its fusibility and decrease its refractoriness. These clays should contain no free silica, provided the ore to be smelted is a basic gangue. However, with a silicious ore, a clay containing a little free silica is an advantage. The character of the ore governs the kind of clays to be used in the retorts in a small way, but it is not so important as many of the other physical properties which a good plastic refractory clay must possess to be suitable for retort-making. From a physical standpoint, the properties of a perfect retort should be maximum heat conductivity, refractoriness, mechanical strength, toughness, minimum porosity and low coefficient of expansion. In a large measure, these properties are dependent upon the raw materials, the size and amount of grog in the batch, the preparation and ageing of the batch, and the methods of manufacture.

Raw Materials.

Bond Clays.—Plastic clay used as the bonding agent in the retort batch should possess a considerable water shrinkage to insure a complete binding together of the grog particles. The refractoriness of clays of this nature ranges between Seger cones 30–31, although a clay of sandy nature which becomes dense at a lower temperature with the property of standing up over a long heat range before showing vesicular structure would not be condemned on account of its low softening point. In fact, many of the clays actually used in the retort industry are only tested to stand above 1630° C. The linear shrinkage of clays used for retorts ranges from about 4.0 to 6.5 per cent after drying, first at room temperature and then at 110° C. The porosity-temperature requirements for these clays would range from 10.0 per cent at 1150° C to approximately 5.0 per cent at 1250° C and to maintain this minimum porosity up to 1400° C before becoming vesicular.

Clays which have been used quite extensively for retort and condenser mixes are found in two localities in the United States—one a dense burning sandy clay from the Woodbridge district, New

Jersey; the other a plastic fire clay of great shrinkage from the Cheltenham district in Missouri. Here one can combine the good qualities of both by mixing the two in the proper proportion. The resultant mix has a softening point slightly lower than either of the original clays, the softening point of a mixture of these clays being lower than the arithmetical mean of the softening points of the two components.

The clays after being purchased from the miners are oftentimes stored in piles in the open, where they go through a weathering and a partial disintegration before they are used. It has been stated[1] that the extra cost of handling and the loss of clay incurred by this method do not justify the advantages gained by the weathering, and in some plants this procedure is not in favor.

The Grog or Chamotte.—Grog, or chamotte as it is sometimes called, may come from several sources. Probably the best grog is the calcined flint clay from the Clearfield district of Pennsylvania. The clay is ground, pugged with water, and ejected from a pug mill in square blocks, which are then dried and burned in an ordinary kiln. These burned blocks are reground and screened according to size, and finally stored for use. The longer life of retorts when the flint clay has been the source of grog leads one to favor this source of grog as the most satisfactory and economical in the long run, notwithstanding the fact that, due to its double preparation, the first cost appears large.

Other sources of grog are old retorts, brick bats, pottery saggers, and salvaged glass pots and tank blocks. In using old retorts for the grog source, one has a chamotte which has undergone a complete change in the furnace through the action of the zinc vapor absorbed in it, which with the alumina of the plastic clay has formed a mixture of zinc spinel and tridymite. This is evidenced by a blue coloration of the clay found in old retorts; this color is sometimes a deep purple. Thus, old material from retorts is of limited refractoriness and mechanical strength. Retorts made from this grog used in large amounts tend to bend and break at high temperatures, so that if the old materials must be used, the proportion of them in the batch should be very low.

[1] C. P. Fiske, *Bulletin A. I. M. E.*, **130**, 1719 (1917).

Of the grog obtained from other sources, such as waste products, that found in old pottery saggers offers the best possibilities, as it has been least contaminated by impurities that would tend to decrease the strength of retorts. Grog from other sources, except new flint clay, tends to have the disadvantage of imparting low mechanical strength to the retorts, and hence, as a result, a larger breakage loss in handling and a lower service record in the furnaces should be expected.

Coke.—Additions of coke dust and pulverized coke up to 10.0 per cent of the batch are now commonly made. This imparts a smoothness to the walls of the retort and gives a greater density and better working properties in the presses. The retort, where coke has been used, has the appearance of a graphite crucible. It has been said that the coke tends to prevent absorption of zinc vapor and diminishes the corrosive action of clays and metallic oxides of the gangue. However, opinions vary regarding the advantages of coke; but, whenever it is present, the shrinkage is reduced and a larger proportion of fine grog can be used in the batch without the danger of excessive cracking. Coke has also been found to increase the density of the vessel. It is the opinion of the writer that additions of domestic graphite may be used to good advantage in the place of coke, provided, of course, that the cost is not prohibitive.

Silica.—Sand has also been incorporated in the batch used in the zinc industries of Belgium and in other sections of the continental zinc industries where a silicious ore is smelted. Where additions of silica to the batch are made, the retorts cost less than those rich in refractory clay and they can be molded with thinner walls, thereby producing a gain in the rate of heat conductivity.

Glazes.—Some retort-makers glaze their retorts with a frit of fluorspar and zinc sulphate. The advantage which is claimed is a denser retort whose inner surface is more impervious to the zinc vapors, cutting down the loss due to filtration and absorption. The action of the frit takes place in the annealing furnace. After the fluorine has been expelled, the retorts assume a very dense inner surface. Mixtures of soda, flint and fluorspar are also used to accomplish this result.

Tests for Retort Clays.

The most reliable test for ascertaining the suitability of refractory clays for zinc retorts is that of the actual service record in the furnace of a large set of retorts. However, this is a lengthy experiment, as considerable time must elapse between the first step in the production of an experimental batch and its final trial in the furnaces, and, again, there are so many outside factors that influence the results that it is often difficult to decide just the exact value of the clay under test. Common factory practice has been to adopt a definite batch once the proper clay and chamotte have been determined for the particular ore smelted. Complete chemical analyses have been found to give little information that would guide the retort-maker in the selection of clays for the refractories. However, there are some physical tests utilized in the laboratory and factory which, the writer has been informed, work very satisfactorily.

At the Palmerton pottery of the New Jersey Zinc Company the following tests are employed to good advantage:[1]

Fusion test, to see whether a clay softens below 1630° C.

Dry shrinkage, linear, at 1230° C.

Burned shrinkage, linear, at 1230° C.

Porosity at 1230° C, as determined by the absorption method over a period of 12 hours.

Tensile strength of clay, 1 weeks' rotting;

Tensile strength of clay, 2 weeks' rotting;

Tensile strength of clay, 3 weeks' rotting;

Tensile strength of clay, 4 weeks' rotting.

In carrying out these tests, the clays are mixed with from 16.6–18.7 per cent of water, to a consistency approximating that used in the pugging machines. Figure-eight molds are used to form the test briquettes; the clay is tamped or thrown forcibly into the mold, and, on removal from the mold, the clay briquettes are allowed to dry at least one day at room temperature and one day at 110° C. One-half of the briquettes are tested for tensile strength and the others are reserved for porosity and burned tensile-strength tests. Along with every test on a new clay or

[1] C. P. Fiske, *Op. cit.*, p. 1721.

grog, a set of briquettes of the standard clay and grog batch is always carried through the test, for the purpose of obtaining comparative data. In all these tests it is the aim to obtain material that gives a superior mix to the standard in present use or to obtain equally as good results at less expense. This being the case, no definite limits have been established except that the clay must not soften below a temperature of 1630° C.

According to Fiske's conclusion,[1] the tensile-strength test is the most important, for it is indicative of the toughness of the vessel, and therefore of its ability to stand handling both before and after burning, as well as to withstand the strains and bumps received during the process of cleaning-out the retort. Tests of the nature of those mentioned are not conclusive, but by standardization and comparison they can be made very useful and will often prevent expensive failures which might otherwise occur in a trial of new materials.

The writer feels that these tests are very good in so far as they go, but submits that a more complete schedule of tests would, in the long run, give more standardized results and complete definite information on each and every clay tested. The tests to which the writer has reference are the following:

(1) Actual softening point of the clays and retort mixes in Seger cones.

(2) Slaking test.

(3) Transverse test on samples dried at 110° C.

(4) Transverse test on samples burned at 850° and 1150–1425° C.

(5) Tensile strength test on sample dried at 110° C, no rotting;

Tensile strength test on samples dried at 110° C, 1 week's rotting;

Tensile strength test on samples dried at 110° C, 2 weeks' rotting;

Tensile strength test on samples dried at 110° C, 3 weeks' rotting;

Tensile strength test on samples dried at 110° C, 4 weeks' rotting.

[1] C. P. Fiske, *Op. cit.*, p. 1722.

(6) Volume shrinkage on samples dried at 110° C, computing these data for comparison records.

(7) Water of plasticity.

(8) Water in terms of true clay volume.

(9) Shrinkage water in terms of true clay volume.

(10) Pore water in terms of true clay volume.

(11) Ratio of pore to shrinkage water.

(12) Apparent specific gravity.

(13) Porosity changes of clay briquettes, drawn at 850–1000° C and at each 50° C interval to 1450° C.

(14) Volume changes of clay briquettes drawn at above-mentioned temperatures.[1]

By following a complete set of tests, all the properties of a clay may be tabulated and preserved, and in a short time one will have certain comparable criteria established, whereby the suitability of a clay for retorts, glass pots or crucibles can be readily ascertained.

Preparation of the Batch.

In the preparation of the batch, the raw materials are ground, separately, in suitable machines, usually dry pans, to pass the required mesh screen. The size of opening for the clay should be 6-mesh and 8-mesh for the grog. After screening, the materials are elevated to storage until used. It is of extreme importance that the proper size of grain for the grog be selected. The grog forms the skeleton of the retort, and its function is to reduce the excessive shrinkage of the plastic bond clay and to regulate the evaporation of the mechanical water, thus helping to prevent the development of cracking during drying. The particles of plastic clays are supposed to be uniformly distributed around the grog grains, binding the whole into a compact mass which gives stability to the refractory retort. The grog also functions to absorb water in the pugging and to gradually return this moisture to the plastic clay during the drying, thereby making the rate of

[1] Procedures for these tests may be found in the Report of Committee on Standards, American Ceramic Society; also see Bleininger and Loomis, *Trans. Am. Ceram. Soc.*, **19**, 601–635 (1917).

evaporation as uniform as possible. As large-size grog particles as possible are to be desired for insuring the property of withstanding sudden changes of temperature to which the retorts are subjected during the transfer from the annealing furnaces to the smelting furnaces, and in the charging of the retorts with new loads. It has been found[1] that by using a judicious selection of grog sizes, and with the same bond clay, the tensile strength of a retort mixture could be increased 50.0 per cent and the porosity noticeably decreased, both being decided advantages. Fuller[2] advocates the use of parabolic formulas in which the diameters of the particles are the abscissa and the percentages are the ordinates. A factory combination of the various sizes of grog approximating Fuller's theoretical conditions consists of:

25 per cent through 10-mesh on 16-mesh,
25 per cent through 16-mesh on 30-mesh,
50 per cent through 30-mesh.

It has been the experience of many clay workers, when attempting to size their grog by mechanical operations, to be handicapped by the moisture variation affecting the operation of the screens. Provided a system of mechanical screening can be successfully developed, there is no doubt but that broader studies in the use of sized grog for all kinds of refractories to attain maximum strength and density will be forthcoming.

Proportion of Raw Materials.—In general, one can state that the clay content of a retort batch runs from 35 to 50 parts; usually 40 is the accepted figure, the remainder being grog. Sometimes the amount of clay is reduced by the addition of sand or coke, or both. The grog usually consists of all new calcined flint bodies or equal parts of new clay with old retorts or brick bats. The flint clay is rarely used raw.

The following commercial batches are presented for comparison:

[1] C. P. Fiske, *Op. cit.*, p. 1724.

[2] Concrete, Plain and Reinforced, Taylor and Thompson, chapter by W. B. Fuller.

	Per cent.	Per cent.	Per cent.
Plastic clay	46.1	40	36
Flint clay	47.8	50	54
Pulverized coke	6.0	10	10
	99.9	100	100

Methods of Mixing and Pugging.—The constituents of the batch, having been ground separately to the required size, are now mixed dry in the predetermined proportions, either by shoveling on a floor, or more commonly, by a mechanical weighing and mixing machine. From the machine the dry mix drops into the hopper of a horizontal pug mill, wherein the proper content of water necessary to develop the plasticity of the clay is added. This amount of water is usually from 8.0 to 10.0 per cent but may run as high as 20.0 per cent. As the clay issues from the mill in a semi-plastic state, it is cut off in large blocks weighing about 60 pounds each. These are loaded on to carts or wheelbarrows and taken to the rotting pits to age. The rotting pits are large brick chambers with no windows or other means of ventilation. Here the material is piled up and covered with damp burlap, and the room is closed off by sliding fire-doors for a period of 3–4 weeks. In this way the clay is allowed to develop its full plasticity. After the material has rotted or aged for the desired time interval, it is taken to the pug mill for another pugging.

It often happens that some of the pugs have been dried on the surface by air currents sifting through cracks in the walls of the damp room, and by re-mixing these pugs there will be obtained uniform working consistency throughout the whole mass of clay before it goes to the machine. During the process of this second pugging the mill operator adds a little additional water or dry retort batch, according to his sense of feeling whether the mix is too dry or too wet, before the pugs go to the presses. From the second pugging the clay batch passes into a vertical pug mill with a horizontal outlet. This machine forms the clay into ballots the correct size and shape to fit the presses. From here, the ballots are elevated to the press floor above by means of a ballot conveyor-elevator and are then ready to be made into retorts.

Before taking up the next step in the résumé, the writer would like to mention the increase and decrease in tensile strength gained by ageing some clays as reported by Fiske.[1] Data reported on this point show the following results for a St. Louis clay dried at 110° C:

24 hours' rotting, tensile strength	67.5 pounds per sq. in.
1 week's rotting, tensile strength	83.0 pounds per sq. in.
2 weeks' rotting, tensile strength	93.0 pounds per sq. in.
3 weeks' rotting, tensile strength	67.0 pounds per sq. in.
4 weeks' rotting, tensile strength	39.0 pounds per sq. in.

Evidently the development of the plasticity up to a certain point is beneficial, but it can be overdone. There is also some question in the writer's mind as to whether the same results would hold true on all refractory fire clays used in the refractory batches. A study of the effect of the temperature of the rotting chambers on the strength of the clays has been mentioned as worthy of investigation but no information along this line has been published to the writer's knowledge. The condition of too much ageing is seldom attained in retort potteries or glass-house refractories plants. Generally speaking, it is the other way. The clay mixes often used come directly from the pug mills with no ageing at all—a condition which one sometimes has to endure to keep the factory output up to the efficiency standard set by administration at the expense of the quality of the product.

The Manufacture of Retorts.

Forming the Retort.—The retorts are most commonly made by auger machines, but in this country some of the big plants[2] use hydraulic presses operating under a pressure of 1800 to 2000 pounds per square inch. The clay is quite stiff when introduced into the presses. This method gives a retort of superior quality: being much denser than the other type, it reduces the loss of zinc by absorption and filtration and increases the strength, rendering the product more able to resist the corrosion of the slags. These retorts are also thinner walled, thus providing a better rate of heat flow and the possibilities of longer service.

[1] C. P. Fiske, *Op. Cit.*, p. 1728.

[2] Mineral Point Zinc Company, Depue, Ill.

Press.—The hydraulic press used for forming the retort, according to Ingalls,[1] consists of a heavy steel cylinder, supported vertically by columns standing on a suitable pedestal. Operating inside of the cylinder there are two rams, one of them being annular and fitting to the main cylinder, the other being cylindrical, working inside of the annular ram. Pressure is exerted on both of the rams from below. The cylindrical ram being central to the machine, its own base serves as the piston. The annular ram is connected with a heavy yoke which is raised and lowered by two pistons working together, one on each side. The cylindrical ram passes through this yoke. Of the four columns which support the main cylinder, two diametrically opposite extend above the top of the latter; the other two extend only a little above the bottom, passing through lugs which are bored out for them. A heavy nut on the end of each column holds the cylinder down securely. The top of the cylinder is closed first by a heavy die block, the shape of the exterior of the retort, and above that a cover plate, both of which are hinged on one of the columns and can be swung horizontally aside by a lever; when in proper position they lock under the nut of the opposite column.

Operation of Press.—In making a retort, a ballot of clay is put into the cylinder from the top, both the die block and the cover plate being removed. The latter are then closed and locked, and both rams together are moved upward, pressing the clay solidly into the cylinder. The inner ram is then forced into the clay, while the annular ram, still under pressure, retreats as the clay is crowded backward around the inner ram. When the clay has been molded, the pressure is held for a minute or two, then it is released for an instant, and the cover plate is pushed aside, and the retort is thrust up and out through the die by the pressure raising the annular ram. The portion of the cylindrical ram which projects inside the die has the shape of the interior of the retort, and the bottom is formed between the ram and the cover plate.

One of these presses will turn out on piece work basis about 320 retorts in 8 hours when operated by a crew of four. A press

[1] "The Metallurgy of Zinc and Cadmium," **1906,** p. 239.

crew consists of four persons, *viz.*, the press operator, press helper, trimmer and trammer, of which two may be women, as is the case in the Mineral Point Zinc Company's plant at Depue, Ill. The press operator's duties are to fill the press with the ballots and to handle the pressure valves which control the press-plunger. After the vessel has been formed and pushed out, this workman cuts it free from the press with a piano-wire cutter.

The press helper swings on and off the die and cover plate and arranges the counter-weighted plate against which the retort is pushed out. As a part of his duty, he cleans out the die and greases it with press oil for the next retort.

As the retorts are cut off from the press, they are put in wood or light metal cases fitting over the lower half of the retort. It is the job of the trimmer to take one of these cases to the press as the finished retort is pushed out. The trimmer places the retort in the case and trims it to a length of 61.5 inches. The date is stamped on and the retort is now ready for the trammer who carts it to the dry room. The trimmer and trammer are oftentimes women.

Drying the Retort.—In a well-arranged retort pottery the dry rooms are on both sides of a long corridor. The rooms are accessible by car tracks running along the corridors in front of the dry room. To insure easy trucking away of the green and dried retorts, a turntable is placed in front of each room, thereby permitting a connection with a track extending the length of the room.

The drying rooms usually have a latticed floor, under which are located the heating coils to furnish the heat for drying the retorts. In the top of the room flues are located, to carry off the excess moisture from the green retorts and to insure circulation of air to expedite the drying. The rooms are closed off tight by sliding fire-doors when completely filled with retorts. The retorts are placed in the room by the trammer, starting at the back of the room first and setting the retorts on their butts close together. When the room is filled, it is closed off and allowed to dry from 50 days to 4 months, depending on operating conditions. The temperature maintained in the drying room is around

52–54° C. In the winter the first steam coil is put on for about a month, then the second one is turned on and left until the retorts are bone-dry. It has been found that the retorts nearest the walls dry more rapidly and show a strong tendency to crack and break. This is probably due to the strong air currents which develop along the walls of the room and to unequal drying conditions of the retorts; this same phenomena is noticed in glass-pot drying.

Storage.—When the retorts are dry they are loaded into trucks and carted to storage rooms, located usually in the furnace buildings quite near the annealing kiln. The retorts used for the next day are taken from the storage to the heating-up or annealing kilns to be burned and transferred hot to the zinc distillation furnaces. The great storage problem is due to the long time interval from the forming through to the drying period. This takes usually 120 days. Thus, in a plant operating 1500 distillation furnaces and having an average breakage of around 3.0 per cent, the total number of retorts required in storage stock all the time would be $1500 \times 0.03 \times 120$, or 5400 retorts. The problem of drying and storing is therefore no small item around the pottery.

Burning.—The burning of retorts is very similar to that of glass pots, except that the period of heat treatment is much shorter. The kilns are of both the up- and down-draft type; the better ones are very much like the modern pot arch and consequently require no detailed description. The number of retorts that must be burned daily depends upon the average breakage in the distillation furnace. This number can be estimated very closely from the records of past experience. The estimated number of retorts is transferred from storage to the kilns during the morning of the day before going into the distillation furnace. The kilns are fired up about noon, gradually at first, and, as the heat rises, the rate of firing is increased until by 5 or 6 A.M. the next day a temperature of 750–800° C has been attained. The work of filling and raking the distillation furnaces begins at 6 A.M. and continues up to 10 or 11 A.M.; during this time any defective retort is removed from the furnace and a new one from the annealing kiln is put in its place. The annealing kilns

are situated in several parts of the distillation furnace room, easily accessible to the furnaces, as the hot retorts are difficult to carry. The usual practice is to place one annealing kiln between two opposite distillation furnaces.

Condensers.—The condensers are not subjected to as severe heat treatment as the retort, they being located on the outside of the furnace proper. Hence, they do not require as good a grade of refractory clay and can be made faster and handled roughly. The condensers are formed by throwing a ball of condenser batch into a conical sheet-iron mold, a revolving water-lubricated pin boring out the clay forming the leg-shaped pipe of clay. After drying overnight, the condensers are crimped over a form, and this crimping causes a bellying out of the central part of the condenser. The crimped condensers are allowed to dry for 2 to 3 days, when they are burned to 900–1000° C. Some plants use as good a grade of clay for their condensers as for their retorts, but it has not been a general practice.

The life of a retort is generally from 30 to 40 days under severe treatment in the distillation furnace. Many break before this time, due to faulty structure and other causes. The number of retorts which have to be replaced daily runs about 3.0 per cent of the total number in the distillation furnaces. The loss of zinc through the walls of the retort by filtration and by absorption into the walls is quite a factor which the chief of spelter of the zinc plant would like to cut down. The machine-made retort and the glazed retort have in a measure overcome some of this loss. However, the absorption of zinc in the retort wall for the first seven days may run as high as 25.97 per cent the first day and as low as 1.7 per cent the seventh day, depending upon the density of the retort and the number of cracks developed therein. The amount of zinc left in old retorts may run from 6.0 to 10.0 per cent.

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A POSSIBLE CAUSE FOR THE DIELECTRIC FAILURE OF PORCELAINS WHICH ARE APPARENTLY FREE FROM MECHANICAL DEFECTS.

PRELIMINARY DISCUSSION.

By Chester Treischel.

From the first uses of porcelain as an insulation in high voltage transmission, difficulties have frequently resulted from the failure of insulators which visually appeared satisfactory, and electrical and ceramic engineers have endeavored to find the cause of these failures and an explanation of porcelain apparently losing its initial dielectric strength without apparent mechanical change.

One of the most widely accepted explanations of this breakdown phenomena is that analogy known as "hammering effect" of the current at high potentials. This analogy, however, becomes somewhat abstract when one asks for a definition of the term "hammering effect." It would seem then that a theory founded on the concrete instead of an analogy founded on the abstract would be a better explanation of electrical failure and would be of greater value to the scientist.

For a number of years it has been known that if crystals of certain substances, such as quartz, are subjected to a pressure on two diametrically opposite faces, these faces being parallel to the major axes, a measurable potential difference is set up, and that this potential difference varies directly as the pressure. This phenomena, known as the piezo-electric effect, was described by Lord Kelvin in two articles appearing in the *Philosophical Magazine*, **36** (1893).

The converse of this phenomena has been found to hold true, namely, that if a potential difference is set up on two opposite faces of a crystal, the sides being parallel to the major axis, the crystal is subjected to a squeezing action.

The application of such a phenomena in explaining the electrical failure of porcelain is at once apparent. Porcelain contains large

quantities of quartz crystals, this fact having been determined microscopically, the crystals being combined together by a glassy magma of fused feldspar. These crystals have no definite position with respect to the direction of their major axes.

Now then, what happens when we subject this porphyritic structure to the influence of alternating high potential? The theory of probabilities will uphold the statement that a number of these quartz crystals are arranged so that their major axes are at right angles to the direction of the flow of the electric current. The current itself is changing its polarity in accordance with the cyclic change, and during each cyclic change there are points of maximum and zero potential difference. If the current is of 60 cycles there will be 120 maximum potential differences and 120 zero potential differences per second. The effect on each individual crystal, which is arranged with its axis in the right direction, will be a vibratory movement parallel to the direction of the flow of the displacement current. This effect could cause breakdown of the dielectric in three different manners: first, a rupturing of the crystals, second, a rupturing of the glassy magma surrounding the crystals; and third, a leakage of current through the voids between the crystals and the magma when the crystal is at its greatest deformation and the potential difference is at its maximum.

RESEARCH LABORATORY,
GENERAL ELECTRIC COMPANY,
SCHENECTADY, NEW YORK.

DISCUSSIONS.

ALBERT PECK: While the writer is aware that in many minerals, possessing so-called polar axes, elastic deformation will set up a difference in potential at the opposite ends of the axes, and that conversely a difference in potential along a polar axis will elastically deform the crystal, he does not feel familiar enough with the phenomena to offer other than a few suggestions which might serve as starting points for further investigation.

In the first place, experiments of the type just mentioned are usually performed on perfectly developed crystals or those artificially produced by grinding. Quartz in porcelain is always present in irregular fragments and never in good crystals so that

if the above principle will not hold for properly oriented irregular fragments, the theory cannot hold. It would seem, however, that the outward form of the quartz is immaterial since we are concerned with directions only. While there undoubtedly would be a few fragments properly oriented with their major axes lying in a plane perpendicular to the direction of the flow of the current, there are also an almost infinite number of possibilities that the greater part are not oriented correctly. It, therefore, becomes a question of whether under the most favorable circumstances these properly oriented crystals would be present in large enough numbers to have sufficient effect to cause failure of the entire body. It is assumed that the author means that the vibratory effect gradually fatigues the fragments until complete rupture of the fragments results. If the fragments do shatter in this way, it seems possible that this could be detected by a microscopic examination of a thin section of porcelain which has failed—as we can similarly observe the shattering of quartz fragments in silica brick.

It is difficult to conceive of a decided change in specific gravity taking place in the quartz without inversion to some other form of silica. While contraction occurs along the axis in the direction of the pressure, there are also two other axes of like character and it seems probable that the contraction in the direction of one axis would be taken up by a corresponding expansion in the direction of the others and equally divided between them so that the volume would not change. Instead of conceiving of a greater density for the fragment, is it not easier to imagine that the fragment may contract in one direction and expand in others against the resistance of the feldspar bond, thus leaving space on one side where the current might leak through?

In passing, attention might be called to the effect of any heating which the porcelain may experience through induction or other electrical effects. Even slight increases in temperature may bring about electrolytic action through the feldspar matrix which rapidly lowers the dielectric strength and electrical resistance of the body.

BUREAU OF STANDARDS,
PITTSBURGH, PA.

E. W. WASHBURN: Since the breakdown of the insulator occurs at comparatively moderate temperatures, it would seem to be improbable that any such explanation as that offered by the author is likely to correspond to the facts—owing to the extremely high viscosity and the corresponding difficulty of moving the crystals in the porcelain body.

If the explanation is correct, a microscopic comparison of the body before and after the breakdown ought to yield confirmatory evidence.

UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS.

W. R. GILDARD: In the burning of porcelain the flux attacks the quartz, taking a part of it into solution while the balance is more or less corroded, as may be seen by a microscopic examination in thin section. This solution is effected by what we may call "washing," firmly embedding the crystal in a matrix of varying silica content. As the crystal is being dissolved there is not the sharp line of demarcation as would be the case if the substance were insoluble (as an illustration, a piece of iron embedded in ice). It appears to the writer that the formation of a void of even microscopic proportions when the crystal is shortened is questionable, but rather that an additional stress is set up in tension.

The theory advanced appears to be an explanation of the "fatigue" and "hammering effects" of the electrical engineers.

According to the work of the Messrs. Curie and of Lord Kelvin, on this piezo-electrical property of quartz, the potential difference is sufficiently large to permit the truth of this proposed explanation being demonstrated in an experimental way.

RESEARCH LABORATORY,
GENERAL ELECTRIC COMPANY,
SCHENECTADY, NEW YORK.

SUBSEQUENT DISCUSSION.

CHESTER TREISCHEL: The uses of a theory, in the order of their importance, are:

1. It is useful in explaining facts as they are.

2. It is useful in forming a basis for the deduction of further facts.

3. It is useful in that it gives intellectual satisfaction.

Granting the above, what facts or phenomena will the theory of the vibration of the quartz crystals in porcelain explain? In what way might it form a basis for the deduction of further facts and for the carrying on of further experimental work?

To the writer it seems that this theory explains the following four fundamental facts:

1. That the substitution of certain substances such as talc, pyrophyllite, sillimanite, calcine, etc., for the quartz in an electrical porcelain, increases the dielectric strength of that porcelain.

2. That porcelains high in feldspar and low in quartz content are stronger dielectrically than those of low feldspar and high quartz content, the amount of clay used in either case being the same.

3. That porcelains tested with high frequency and with low frequency current at the same high potential, show that the disruptive effect of the high frequency current is much greater than that of the low frequency current.

4. That porcelains tested with direct or alternating currents at the same potentials show that the alternating current has a much greater disruptive effect than the direct current.

The replacement of the quartz in electrical porcelain with various substances has been attempted many times in an experimental way. In every case with which the writer is familiar, such a replacement has resulted in an increased dielectric strength. Even iron oxide in small quantities produced gratifying results. In this case, the amount of quartz present is materially reduced by the substitution of some substance for it. This substance being inert piezo-electrically, there of course is no crystal oscillation during the electrical test and the result is a porcelain of greater dielectric strength.

The same is true of the second case except that we do not have a complete substitution, but rather a partial replacement of quartz by feldspar. The piezo-electric effect, however, applies equally as well since there is a smaller number of quartz crystals present and consequently a smaller number of them properly oriented.

In explaining the greater disruptive effect of high frequency current over low frequency current we have in the case of the high frequency a greater number of pulsations per second than with the sixty cycle current. This no doubt fatigues the crystals more rapidly, causing a quicker rupture, just as in the case of the rapid and slow bending of a piece of steel we have the rapid bending causing the damage first.

With the use of direct current we have something of the same effect as that noted with the use of low frequency, the frequency here being zero. Of course, there is no vibration of the crystal in this case, merely a squeezing action—consequently a less violent effect upon the porcelain and noticeably greater dielectric strength than with the alternating current.

Now then, in what fields of further research will this theory lead us? It seems to the writer that there are two large and important ones, *viz.*:

1. The development of a substitute for flint which will not interfere with the proper working and burning of the porcelain batch. In other words, we want a material which has all of the good qualities of flint and enough inherent good qualities of its own to overshadow the bad qualities of flint.

2. The development of a feldspar substitute which will have all of the desirable fluxing and dielectric properties of feldspar but at the same time will be more elastic and less brittle.

THE TECHNIQUE OF OPTICAL GLASS MELTING.

By Clarence N. Fenner.

Without going into a full account of the circumstances which led to the coöperation of the Geophysical Laboratory with the manufacturers of optical glass of the country it will be desirable, as an introduction to this article, to summarize our activities in brief form.

Our coöperation began about the end of April, 1917, when certain members of the staff of the Laboratory were detailed to the plant of the Bausch & Lomb Optical Company at Rochester, New York. In December, 1917, the coöperation was extended to the Spencer Lens Company's plant at Hamburg, N. Y., and to the Pittsburgh Plate Glass Company's plant at Charleroi, Pa. At all these plants active coöperation continued for many months, and, with the last two, until the close of the war.

At the Bausch & Lomb plant the men from the Geophysical Laboratory had from the beginning the benefit of the many years' experience in glass-making of Mr. Victor Martin, chief glass-maker there, and the advantage of entering a works in which many of the difficulties attendant upon the first stages of starting up a new technical process had been surmounted. These facts were of the greatest assistance to us in becoming familiar with many details of practical glass-making, and further advances were thereby much facilitated. Although descriptions of ordinary glass-making operations were to be found in the literature, almost nothing had been published regarding the numerous important details in which the making of optical glass differs from that of other glasses.

At about the time that the work of the Laboratory was extended to the other plants, arrangements with the companies assumed a somewhat different form. At Rochester a more direct supervision of furnace operations was exercised; at Hamburg the Spencer Lens Company placed the entire operation and super-

intendence of its plant unreservedly in the hands of the Laboratory men; at Charleroi the supervision of the furnace-floor operations, in so far as the production and treatment of optical glass were concerned, was likewise placed in their charge.

The problems with which we had to deal were very different in many respects from problems of scientific research. Our task was essentially this: To produce as a matter of daily routine, glass in large quantities and free from serious defects; to seek constantly to eliminate defects and increase percentage of yield per pot; and to add to furnace capacity as rapidly as possible in order to meet the insistent demands for quantity production of good glass. The last requirement was always before us and practically everything else had to be subordinated to it. Problems of scientific importance, no matter how interesting, had to give way if they did not lead to the main object in view.

Because of the fact that the Laboratory men were at work at three different plants, among which conditions were, in some respects, quite dissimilar, experiences varied. By interchange of ideas this fact worked to the benefit of all. During the whole period under consideration the technique of the making of optical glass was in a state of change and development. New ideas which occurred to one or another were tested, and either rejected or, if found to be an improvement, were adopted as part of the routine of operation. From a consideration of this process of evolution it will not be a matter of surprise to anyone that the stage which has been reached at the present moment is not to be looked upon as the final stage of evolution, or that it is expected that no further progress will be made. It is fully realized that many problems of importance still remain for solution, but it is a source of great gratification to us that we have assisted in some measure in the production of thousands of pounds of optical glass of a quality equal to the demands imposed by military requirements, and much of it, as rigid tests show, not surpassed by the product of the more famous foreign works.

It would be beside the mark to describe the stages by which the present technique of optical glass melting has been evolved. It is rather the purpose to describe it at the stage which it has reached at present in its course toward more perfect development.

The description will be based not alone on individual experience but on the experience of all the men of the Geophysical Laboratory who took active part in this phase of the work. Those who were connected most directly with the operations which form the subject of this article were L. H. Adams, N. L. Bowen, C. N. Fenner, J. C. Hostetter, G. W. Morey, and F. E. Wright.

This article will deal with the melting process and closely allied operations. Particular attention will be given to those details of practice in which the melting of optical glass differs from that of other glasses, but in order to present matters in connected form it will be necessary to give an account of operations in the sequence in which they occur, even though this may involve some description of processes with which all glass-makers are familiar. It is not the purpose to emphasize any matters with whose development the members of the Geophysical Laboratory were especially concerned, but rather to present, for general information, a plain description of processes which have been found satisfactory in the making of optical glass. Other phases of the work connected with the preparation of optical glass will be treated by other writers in separate articles. Some of these have already appeared and others are being prepared at the present time.

Preliminary Operations.

An essential need in making good optical glass is pure raw materials. Especially important is freedom from those metallic oxides which impart color, such as iron, nickel, and manganese, and freedom from such impurities as sulphates and chlorides, which tend to produce milkiness or opalescence in glass. A full consideration of the requirements which the raw materials must satisfy will be given in detail in another article. It is sufficient at this point to say that the glass-maker must know beyond doubt what goes into his batch, and this can be done only by frequent chemical analyses.

It must be realized from the beginning and borne in mind constantly that, from the standpoint of the purposes for which optical glass is to be used, it has little in common with other kinds of glass. In order to serve its purpose an essential requirement is

that its optical constants should be definitely fixed and maintained. Other requirements of a similarly exacting nature must also be met, and it is possible to do this only by the most careful control throughout the process of manufacture. It would not be amiss to compare the precautions required in the making of a pot of glass to those which must be exercised in making an exact quantitative analysis.

The batch is mixed in a long, open box of such capacity that the whole may be shoveled from a pile at one end to a pile at the other in the process of mixing. It is best to use broad, flat wooden paddles or grain-scoops for this purpose, rather than iron shovels. The amount of iron which would be added to the batch by the wear of iron shovels is probably extremely small, but wooden paddles or scoops are as easy to use for the purpose of mixing, and it is better to avoid iron tools where possible if only to impress the workmen with a proper appreciation of the dangerous qualities of iron.

The batch must be so well mixed that any portion which is left over after filling a pot will not differ appreciably in composition from that which has been used. This will be secured by shoveling the material at least three times from one end of the box to the other with a turning and spreading motion. At some stage during this mixing, preferably after the first transfer from end to end, the whole should be passed through a sieve of four to six meshes per inch, which rests in a frame at one end of the batch-box.[1] This will remove nails, chips, and so forth, and will insure that no batch-material is left in a lumpy condition. If the scale of operations is large enough to warrant it, some form of mechanical mixer may be used. In any case care should be taken to see that the mixing of the batch is so thorough that any appreciable fraction does not differ in composition from the whole. After the batch has been mixed it may be left in the batch-box until it is used, if operations are conducted in such a manner that only a short time will elapse, or it may be stored in a bin. A discussion of questions of this kind, however, is rather apart from the purpose of this paper. They are matters of considerable

[1] It would really be better to put all materials through sieves before adding them to the batch, as well as to make a sieving at a later stage.

importance in works-management, but are not peculiar to optical glass-making.

Attention should be directed to one matter at this point—the care which should be exercised to keep different batches separate. Any confusion in this matter is likely to lead to a chain of serious consequences which will not be broken until all stock on hand of possibly contaminated batch has been thrown away, and all glass produced from it (which is not usable even as cullet) likewise disposed of.

In order to carry out completely the idea of avoiding contamination we should have at least three batch-boxes, one to be used for crown glasses, a second for flints, and a third for dense barium crowns. Moreover, it is well to sweep out the batch-box each time before use. It may seem somewhat trivial to emphasize apparently unimportant matters like these, but it is by paying attention to details of this kind and establishing a standard of careful procedure throughout all steps of manufacture that the qualities essential to optical glass can be maintained.

Considerable leeway is permitted to us in the matter of the form of combination in which a given ingredient of the glass is added to the batch, but in some cases compounds which, at first sight, might appear unobjectionable are found to be limited in usability by certain qualities which they possess. As a source of K_2O we have the carbonate, bicarbonate, and nitrate. The sulphate is out of the question because of its tendency to segregate as a layer of "salt water" on top of the melt and because it has the effect, even in small quantities, of inducing milkiness in some glasses.[1] KCl is objectionable for similar reasons, and also because of its volatility. Commonly, most of the K_2O is added in the form of carbonate with a very appreciable percentage of nitrate (say 25 to 33 per cent of the alkalis in the latter form). The nitrate produces oxidizing conditions during the thermal dissociation and recombination of the batch ingredients and this is

[1] J. D. Cauwood and W. E. S. Turner, "The Influence of Small Quantities of Chlorides and Sulphate in Producing Opalescence in Glass," *Jour. Soc. Glass Tech.*, **1**, 187 (1917). C. N. Fenner and J. B. Ferguson, "The Effect of Certain Impurities in Causing Milkiness in Optical Glass," *J. Am. Ceram. Soc.*, **1**, 7, 468 (1918).

a highly desirable function. If it be used in large quantities, however, there is danger on this score: that at a temperature which is considerably below that at which there is active combination of the basic oxides with silica the nitrate will be decomposed into a highly caustic liquid which is likely to segregate from the rest of the batch and attack the pot. For this reason it should not be used ordinarily in quantities greater than those given. At Charleroi, however, the Pittsburgh Plate Glass Company use a pot of their own manufacture which seems especially resistant to this corrosive action. This, combined with the fact that large quantities of cullet are added to the batch, enables them to replace even the whole of the carbonate with nitrate. They are thus able to avoid the several somewhat objectionable features of the carbonate. The bicarbonate has been said by some to cause difficulty in fining, but we have used a considerable quantity of it in pots of medium flint and baryta flint without any observable deleterious effects.

In most glasses the replacement of K_2O by an equal weight of Na_2O has not a great effect on refractive index or dispersion. As the price of potash compounds is ordinarily greater than that of soda compounds and has recently been very much higher, the total substitution of soda for potash would offer decided advantages from that standpoint. Unfortunately it does not seem that this may be done without evil effects ensuing. The use of a certain amount of soda seems to be desirable, as it probably increases fluidity, but according to general opinion (for which there seems to be some basis) the use of large quantities tends to increase the color. The amount to which Na_2O may be used without injurious consequences varies with the composition of the glass. Frequently in the common glasses it may be used in amounts equal to those of K_2O, but if the glass has a tendency to show more depth of color than is desirable it is better to keep the Na_2O down. Such glasses include those high in lead or high in barium. In a baryta flint which was made regularly at Hamburg (a glass containing about 38 per cent PbO, 6.5 per cent BaO, and 3 per cent ZnO) the alkali used was wholly K_2O. When we tried a batch containing Na_2O to K_2O in the ratio 1 : 1.18 the color was distinctly increased. Other evidence of the color-

inducing effect of Na_2O has also been obtained. For this we have not been able to find a wholly satisfactory explanation. It does not seem likely that the soda itself gives color, but that the effect is secondary. Possibly a large quantity of soda causes greater corrosion of the pot and leads in that way to a larger amount of iron in the glass, or the same amount of iron may show up more in a soda glass, or the soda used may contain a small amount of sulphide or other reducing material which causes more of the iron to assume the ferrous form and therefore exert a more powerful coloring effect. It would be of considerable interest to settle this question, although the present commercial incentive arising from the abnormally high price of potash may partly disappear. A great deal of information on the relative quantities of K_2O and Na_2O used in the Schott works at Jena may be found in Zschimmer's tables.[1] However, a study of the syntheses appearing there gives very little insight as to the principles on which the relative amounts of K_2O and Na_2O used were based. They seem to be almost haphazard. A little later in this article batches for a number of typical glasses made in this country will be given, and these will show the amounts of Na_2O which we considered safe to use.

As a source of lead for flint batches either red lead (Pb_3O_4) or litharge (PbO) may be used. Red lead contains a little excess oxygen and might for that reason be considered preferable. Practically there seems to be no difference. After observing the results obtained from a great number of batches, some made with red lead and some with litharge, subjected to the same furnace conditions, we have not been able to see that there is any choice between them. It will simply be a question of purity of material and of price (calculated on the basis of lead content).

With most of the raw materials the size of grain has little effect on melting, and as long as the material is not lumpy the size of grain gives us little concern. With sand, however, the processes of combination and solution during melting are slow, and if unduly prolonged (as when the sand is coarse) the consequences are bad in several respects. The length of time which a run

[1] E. Zschimmer, in "Handbuch der Mineralchemie, herausgegeben von C. Doelter," article "Glas." Bd. I, p. 855.

takes is increased; there is more opportunity for liquation of the easily fusible materials, leaving the quartz floating on top; and slow melting is likely to mean poor fining. Therefore, quartz sand of coarse grain is undesirable. A very satisfactory sand which has been used largely at all three glass plants was of a size to pass through a 35-mesh Tyler standard screen.

The Use of Cullet.

In all optical glass making a large proportion of the glass in a pot is rejected because of defects of one kind or another. Thus a large quantity of glass which is not of optical quality but which represents considerable monetary value simply from the materials used in making it is likely to accumulate. The defects which have caused rejection are likely to be bubbles and striae. By putting this glass through the melting process a second time under proper conditions the percentage of saving in good glass from this cullet will probably be as high as in glass made from a new batch. We should, therefore, consider the manner in which the cullet may be used.

A first and very obvious requirement is that each type of cullet should be kept separate. Moreover, glass which is very stony or contains other defects which will probably not be removed in remelting should be rejected entirely. Milky or opalescent glass, however, which is otherwise suitable, may be used without fear. On the other hand, it must be remembered that certain properties of the glass will be changed each time it is remelted. It will take up more and more iron and other material from the pot, which will increase the color and change the index. Selective volatilization likewise will affect the index. These last-mentioned factors are likely to be the effective ones restricting the amount of cullet which it will be wise to add to a batch. It is quite feasible to make melts of cullet only, and indeed this has frequently been done, but there is likely to be some deterioration of the glass from standard quality under such conditions.

The changes consequent upon remelting will be different with the different types of glass so that no exact figures can be given as to percentages of cullet which we may add. Probably in heavy lead glasses the effects will be more marked than in other

common types. The standard of quality which is aimed at and the general care with which operations are conducted will likewise affect the question. If to a batch which is supposed to give a glass having $n_D = 1.605$ and $\nu = 37.7$ there is added 30 per cent of cullet which is supposed to be of the same type but which in reality has $n_D = 1.603$ and $\nu = 37.9$ we cannot expect to get exactly what we want. The essence of the matter is that there is no special trouble of operation arising from the use of almost any amount of cullet, but as for the amount that the manager will use, that will be decided by the way in which the properties of the cullet which he has on hand correspond to those of the glass he is trying to get.

For ease of handling the cullet should be broken up. This may be done simply with a hammer, but labor is saved and a better job is made by passing it through a jaw crusher. The jaws need not be set to crush very finely. We merely wish to get a shaly mass which can be shoveled without trouble. After this crushing the material should by all means be passed over a magnetic separator. A surprising amount of iron gets into the glass from the jaws of the crusher, but most of it is easily removed magnetically. In using the cullet it may either be mixed with the batch or filled in with it in alternating layers.

Setting the Pot and Filling in the Batch.

We will suppose that a pot of glass has just been removed from the furnace and we are about to start a new run. We will suppose also that the furnace we use is a reverberatory furnace operated on the regenerative principle. This is the type used by the Bausch & Lomb Optical Company and by the Spencer Lens Company. At the Charleroi plant of the Pittsburgh Plate Glass Company some of the optical glass is made in non-regenerative stackless furnaces of approximately cubical shape, heated by a blast, and some in large regenerative furnaces of twenty pots capacity each, such as are used for making plate glass. In all these types of furnaces the glass-making operations proper are essentially the same. The chief point of difference lies in the ability to control the conditions to which each pot is subjected, and in that respect the single-pot regenerative furnace seems to

offer considerable advantages. The description which follows will be based upon the operation of such a furnace. In many cases the portions of the description which are not applicable to the other types will be readily eliminated by the reader who is familiar with furnace operations, but where it seems desirable the description will be supplemented by an account of the modifications of procedure which are necessary in other furnaces. However, the endeavor will be to point out and emphasize the salient features in furnace conditions and operation which are desirable in making optical glass in distinction from other kinds of glass rather than to consider in detail the design and construction of furnaces which are necessary for the attainment of these results.

The first operation is to get the "siege" or floor of the furnace in good condition for the next run. This operation, however, is common to other kinds of glass-making and a description will be omitted. Likewise we shall pass over the transfer of the new pot from the arch in which it has been heating to the furnace, merely remarking that it is important to see that when the pot has been placed in the furnace it rests level on the siege. When these preparations have been finished the fire which, several hours before, had been shut off, is started again, and the furnace is brought up to melting temperature.

We will suppose that the previous pot was taken out of the furnace about the middle of the afternoon and that the operations referred to have been finished about four P.M. As will appear immediately, working conditions will often make it desirable to run on about this schedule, although this will not of necessity be the case. The furnace has become fairly cold, as no fire has been burning for several hours, and until the temperature is brought up again there is a hiatus in operations. Therefore the temperature is raised as rapidly as possible. Under the best conditions this will take considerable time, and if the gas pressure is not satisfactory seven or eight hours may be required to reach 1400° C. In some cases this may be more of a loss than is evident at first sight. Unless the plant be a very large one, employing great numbers of men at all hours of the day and night, the working arrangements will probably be such that pots will

be finished and taken out at about the same time each day. This will probably render it impracticable to base operations on anything but a twenty-four or a forty-eight hour schedule. Until recently forty-eight hours has been considered the normal length of time for completing a run. It was evident that the time could be shortened considerably, but unless it could be brought down to twenty-four hours there was not much incentive to curtail operations. Recent operations at Hamburg, however, have shown that in most cases it is perfectly feasible to work on a twenty-four hour schedule and produce just as good glass. To accomplish this it is essential that there should be no long delays anywhere. Therefore, the importance of having a good supply of gas and bringing the temperature up rapidly is evident. In doing this the beneficial effects of exposing the pot to a prolonged baking and sintering have to be sacrificed in some measure, but if by making this sacrifice the run is shortened to twenty-four hours the advantages are in favor of this procedure. At Charleroi the conditions are such that there has been no necessity of choosing between twenty-four and forty-eight hours. The optical glass plant is run in conjunction with an establishment having a very large output of plate-glass, and a large number of men are available on all shifts throughout the twenty-four hours. Other considerations exert their influence here, and the result is that the schedule aimed at has been twenty-seven to thirty hours in length. A description of the practical details of the twenty-four-hour schedule and the conditions under which it is applicable are given in the article by G. W. Morey in this number.

After the temperature has reached 1400° C, it is held there for about one hour in order to complete the baking of the pot and cause it to assume the dense condition which it must have to resist the corrosive action of the glass.[1]

A word may be said here about the means of determining temperatures in glass-furnaces. Proper temperature regulation is a matter of the very greatest importance in making optical glass, and an exact and reliable method of measurement is essen-

[1] Even higher temperatures (1430°–1440°) have been used with good results.

tial. The old method of regulating temperatures by the eye is hopeless. Undoubtedly some men who have had years of experience become remarkably proficient in this respect, but even the best have their off-days. Thermoelements are now much in use, but as shown in a previous article,[1] they are not very reliable for this work. An optical pyrometer meets the requirements much better, and is probably the most satisfactory instrument for glass-furnaces that we have. A detailed discussion of this matter and a description of the use of such instruments will appear later as one of the articles of the present series.

Although thermoelements are unreliable as standards, it is nevertheless very convenient to have each furnace equipped with one. Their changes of calibration are likely to be slow, and if the readings are controlled occasionally by an optical pyrometer, they may be used for ready reference.

The furnace having reached the condition described, the pot is glazed with cullet. The object is to have the pores filled with material of the same composition as the glass which will be made in the pot. If this be not done, but batch-mixture be the first material put in, the most fusible and at the same time most corrosive elements of the batch will enter the pores and possibly effect a disaggregation of the pot-material, which will subsequently lead to leakage or stones.

At least three or four scoopfuls of cullet are used, and it is best to pour it around the inside of the pot and allow it to run down to the bottom. The quantity should be sufficient to form a pool at the bottom, and if a large amount of cullet is on hand and is to be disposed of, it may be added in much larger amount than mentioned. The pot is then allowed to stand one hour longer. By holding the furnace for two hours at 1400° C before starting to fill in the batch proper we have made sure that all parts of the furnace and regenerative chambers are well heated and that the heat has penetrated the furnace lining to such a depth as to make available a certain store of heat for aiding in

[1] C. N. Fenner, "Methods of Temperature-Control in Glass-Melting Furnaces," *Phys. Rev.*, 2nd series, **11**, 2, 141. Abstract of a paper presented at the Rochester meeting of the American Physical Society, October, 1917.

a quick melting of the batch. The quicker the batch melts down the more satisfactory is the fining likely to be.

The normal quantity of batch to put in in the first fill is that which will about half fill the pot with unmelted batch. If the glass is one which is apt to give trouble in fining it is well to use a less quantity in order to give quicker melting, and fill in oftener.

When the first fill has melted down to a level surface, or in about three hours, a second fill of the same quantity is put in,

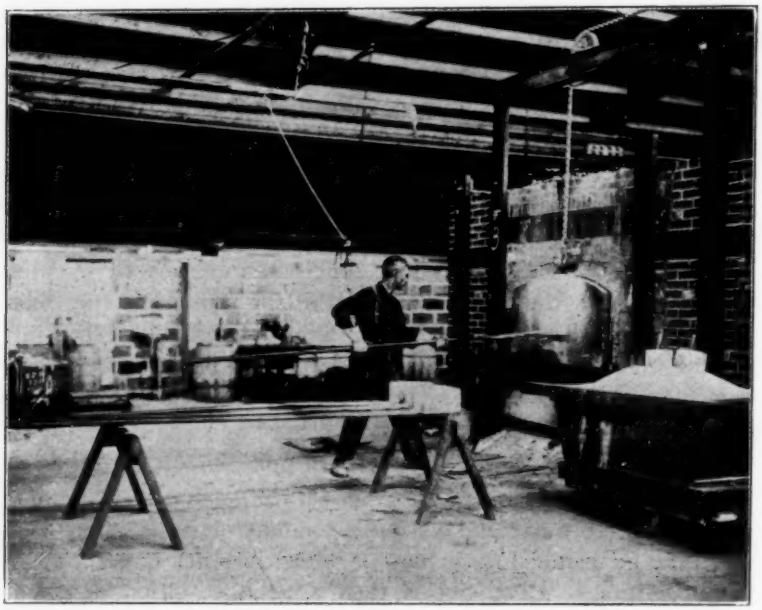


FIG. 1.—Filling in the batch.

and three hours later a third fill. Then one after another smaller fills are added, and finally the melt is topped off by a few scoopfuls of batch. The level at which filling ceases is that at which the melt is an inch or an inch and a half below the rim of the pot. The operation of filling is illustrated in Fig. 1.

Melting and Fining.

During melting such volatile substances as water, carbon dioxide, and oxides of nitrogen, likewise the excess oxygen in red lead, are driven off and the bases unite with silica (and with boric oxide, if that is present). A few moments after a fill is put in we may see little eruptions of gas, given off here and there from the batch, breaking through the liquefied surface. On the whole, however, the melting process is rather quiet. The presence of niter insures that the conditions shall be oxidizing, and gives the melt a fair start in the right direction in that respect. It is our business to see that the subsequent history does not involve reduction. That is a matter of keeping the furnace atmosphere in proper condition, and will be discussed later. Most of the volatile gases given off in melting escape entirely, but a relatively small amount is entrapped as bubbles, and another portion, there is reason to believe, is dissolved by the molten glass. The combination of the basic oxides with silica is likely to be slow, and as the silica is of relatively low specific gravity, this gives an opportunity for gravitative differentiation. In flint glasses especially a surface layer containing large quantities of grains of undissolved silica is likely to persist for a long time. In very dense flints a bottom layer of excessive lead content is also formed.[1] In one striking case which came under observation a pot of glass, which was supposed to have an index of 1.648, showed, because of improper stirring, the following phenomena: At the bottom a distinct layer, of about a foot in thickness, of glass of a pale greenish-yellow color, having an index of about 1.690; above this a mass of glass in which the index varied from 1.630 in the lower portions to 1.610 in the upper. During the melting of this glass samples from the top had shown quantities of silica grains embedded in a glass having an index of about 1.545. Probably in most cases a glass of this kind has undergone a similar segregation, but in this example the subsequent procedure was faulty and the segregation was not destroyed by stirring. Possibly, also, in this case the fills were not given time to melt down

[1] Liquation is naturally less pronounced when a large amount of cullet has been added before the batch is filled in.

sufficiently before others were added. In a paper by N. L. Bowen[1] phenomena of this nature are discussed in some detail.

It has been held by some who have made observations on gravity-separation effects in glasses that the evidence points to liquid immiscibility, but to anyone who has studied the phenomena of glass-making for a long period and who has been able to make observations at all stages of the process this explanation appears entirely unwarranted. Nothing seems more certain than that, if the mixing is sufficiently thorough, a homogeneous solution is formed, and that it is only by subsidiary processes, such as volatilization from the surface and solution of the pot walls, that there is a tendency for the glass to become inhomogeneous later. It is necessary, however, that such compounds as chlorides and sulphates be excepted, for the solubility of these in the melt is undoubtedly rather small. Instead of forming a homogeneous solution they rise to the top and form immiscible layers.[2]

The filling and melting will probably take eight to ten hours. Ordinarily this will be followed by a period of several hours during which the melt is allowed to stand and fine. However, according to the twenty-four-hour schedule it has been found possible in most cases to dispense altogether with fining as a separate process. The glass is given a hand-stirring before the melting is really complete. Then, a short time after the last fill, the machine-stirrer is set in operation and stirring continued until the pot is ready to come out.

During most of the fining period the glass is allowed to rest quietly. Filling has taken, we will say, from 10 P.M. to 8 A.M. Two or three hours later most of the surface of the glass should appear smooth and mirror-like, but if a proof or sample be taken the glass will be found to contain numerous large and small bubbles. Gradually the quantity will diminish. The large ones will disappear first. There is usually a period during which the evolution of large bubbles is quite active and this effect is termed the "boil." The fine bubbles ("seed") will continue rather longer

[1] N. L. Bowen, "The Significance of Glass-Making Processes to the Petrologist," *J. Wash. Acad. Sci.*, **8**, No. 4, p. 88 (Feb. 19, 1918).

[2] See F. Gelstharp, *Trans. Am. Ceram. Soc.*, **14**, 665 (1912).

than the larger ones but, if matters go properly, they should disappear almost entirely within a few hours. Occasionally a pot of glass will, for some reason, show a persistent layer of froth on top. One dislikes to see this, but nevertheless, such a pot will frequently come out all right in the end.

During fining the direction of flow of the air and burnt gases through the regenerative chambers should be reversed often enough so that one side does not become chilled and the other overheated. Reversal at intervals of twenty minutes answers very well for this.

For most of the common types of glasses a temperature of about 1400° C during melting and fining is required. If the batch materials contain sulphate or chloride in any but very small amounts and the glass is one which is likely to turn milky because of these impurities,[1] the danger may be avoided by keeping the temperature at 1420–1430° C during these operations.[2] This temperature is somewhat severe on the pot and the danger of the pot leaking or casting stones is increased, but pots are now manufactured in this country of such quality that, with proper care in previous treatment, the risk of disastrous consequences from running at this temperature is not so great that it need cause us to hesitate. It is essential, however, to see that, through carelessness, the temperature does not rise 15 or 20 degrees higher than the point established. Excessive temperatures are not only hard on the pot but increase the amount of selective volatilization from the surface and thus tend to alter the index of the glass.

Under ordinary circumstances (that is, when there is no danger of milkiness) a temperature of 1400° for a light flint or a boro-silicate crown answers very well. An ordinary light crown forms a more viscous melt and may be run at 1410°. Dense flints are very liquid, and need not be heated to more than 1370°.

Zschimmer[3] gives the following as the melting temperatures used at the Jena works:

[1] Light flints seem especially susceptible.

[2] C. N. Fenner and J. B. Ferguson, *Op. cit.*

[3] E. Zschimmer, *Op. cit.*, p. 865.

1000° C Phosphate glass ($3B_2O_3$, $70.5P_2O_5$, $12K_2O$, $4MgO$, $9Al_2O_3$, $1.5As_2O_3$, according to synthesis).

1100° Dense lead silicate glass ($20.8SiO_2$, $79PbO$, $0.2As_2O_3$—Syn.).

1130° Borate glass ($52.5B_2O_3$, $1SiO_2$, $1.5Na_2O$, $1.5K_2O$, $6ZnO$, $12BaO$, $16PbO$, $9Al_2O_3$, $0.5As_2O_3$—Syn.).

1320° Dense barium borosilicate glass ($14.5B_2O_3$, $39SiO_2$, $41BaO$, $5Al_2O_3$, $0.5As_2O_3$—Syn.).

1370° Ordinary flint glass ($45.7SiO_2$, $1.5Na_2O$, $7.1K_2O$, $45.4PbO$, $0.3As_2O_3$—Syn.).

1410° Ordinary crown glass ($2B_2O_3$, $69.2SiO_2$, $8Na_2O$, $11K_2O$, $4CaO$, $3.5ZnO$, $2PbO$, $0.3As_2O_3$—Syn.).

Where a covered pot is used, having only a comparatively small opening in front through which there is any possibility of furnace gases reaching the melt, the atmospheric conditions in the furnace around the pot are not of very great importance. Volatile materials, such as lead oxide, alkalis, and boric acid, are evolved and supply a protective covering within the hood of the pot, and through this protective atmosphere the furnace gases seldom penetrate. On the other hand, if open pots be used, it is important to keep reducing gases away from the glass. If the conditions within the furnace are kept anywhere near right the reducing action will never be sufficient to precipitate metallic lead, but at a considerably less intensity of reducing conditions the ferric oxide will be partly changed to ferrous oxide, and the same amount of iron in this lower state of oxidation has a much more intense coloring effect. In order to avoid this the gas should be burned with a rather short flame. A criterion which may be used is to see that the visible flames do not extend much beyond the top of the crown. Slowly moving flames, curling down over the pot, should be avoided if possible. In a multiple-pot furnace it may be difficult at times to avoid contact of the flames with the surface of the melt, but in single-pot furnaces, especially of the regenerative type, matters are under control to a greater degree, and here we may quite easily keep the temperature at the desired point and at the same time have the proper kind of flame by making correct adjustment between amount of gas, width of opening of air-inlet, and pull of stack, and a good furnaceman will soon learn to keep things very steady after having been shown what conditions are required. Some difficulty may be ex-

perienced at first in getting him to understand that economy in combustion may occasionally have to give way to other requirements.

Different types of glasses show considerable differences in the facility with which they free themselves of bubbles. For those glasses which give difficulty in this respect an old practice, which has been applied commonly not only to optical glasses but to other kinds, is "blocking." This consists in introducing some substances below the surface of the metal which will quickly evolve vapor. The large bubbles which are given off and rise through the metal tend to sweep out smaller bubbles with them. For this purpose various substances have been used—a block of wood, a potato, arsenic, etc. The Pittsburgh Plate Glass Company has developed the use of a substance which is especially applicable to optical glasses. A small amount of ammonium nitrate, sufficient to give rise to a number of large bubbles when it is inserted below the surface of the metal, is wrapped in paper so as to form a package. This is fastened to an iron rod which has been bent at almost a right angle, and plunged quickly into the metal and down to the bottom of the pot.[1] The ammonium nitrate is rapidly volatilized and the vapor rises in several great bubbles.[2] The blocking is begun when the metal has reached an open boil, at which time the operation is carried out three times in rapid succession, and fifteen minutes later three times more. This is continued until the metal is "plain" or free from bubbles. The fact that the vaporization of this substance is complete and without residue, and that the gas is oxidizing in character makes this material almost ideal for the purpose. Besides its effect upon enclosed bubbles it probably aids mixing somewhat by throwing up any heavy layer that has settled to the bottom.[3]

[1] We need have no hesitation in inserting iron tools temporarily in the melt if we see to it that their surfaces are kept free from scale.

[2] Instead of enclosing the ammonium nitrate in a paper wrapper it is sometimes melted over a low flame and cast in "pencils" in a mold. A section of one of these "pencils" is fitted into a cylindrical receptacle on the end of the rod and used as before. This method is rather neater and seems preferable, but it necessitates a little previous preparation.

[3] At Hamburg, in running on the twenty-four-hour schedule, it has been found effective in some cases, when the fine bubbles will not clean up, to stop stirring, turn off the gas, and drop the temperature from 1400 to 1250°, then turn on the gas, heat to 1400°, and resume operations.

The period of quiet during fining gives opportunity not only for the bubbles to rise but for pot-stones also to come to the surface. With a good pot the amount of stones cast should be small and often is negligible. If they appear they will be removed later by skimming.

Bubbles and Their Origin.

One of the chief purposes served in fining is the elimination of bubbles. It seems opportune, therefore, to discuss at this point the origin of bubbles, although such discussion will involve to some extent a reference to subsequent processes.

There are several obvious methods by which bubbles and seeds are formed, and others which are more obscure. Likewise the removal of some kinds of bubbles (or the bubbles in some glasses) gives no special difficulty, while in other cases the difficulties are very great. There are phases of this problem which have given us much concern and some questions regarding which we do not feel that we can give a definite and satisfactory answer. There are one or two types of glass which still give an occasional pot with many "seeds" (small bubbles) in spite of all precautions.

The great majority of the bubbles are doubtless entrapped mechanically, but others appear to be set free from solution in the glass. Of those entrapped mechanically many are to be referred to the first melting of the batch. With these the best possible opportunity for escape is offered during the period of fining, when the temperature is high and the glass is in its most liquid condition, and most of them should escape at this time, especially if assistance be given by blocking. We find, however, that often with the rather viscous melts, such as light crown, and less frequently with other melts, quantities of bubbles collect on the walls of the pot and adhere tenaciously. A proof taken after the first hand-stirring will often show many bubbles which have been set free by the agitation and have arisen to the surface, though prior to the stirring the glass may have seemed free of bubbles. These are probably to be attributed in part to gas which has been clinging to the walls and in part to gas which has been dissolved in the melt beyond the point of saturation and has

been set free by the mechanical agitation. In general, bubbles which have been entrapped during melting are not likely to be so troublesome as to cause us much anxiety. Certainly that is true with the more fluid glasses and probably with even the more viscous.

A second kind of mechanically entrapped bubbles are those which are stirred into the glass. During the last stages of stirring the viscosity of all glasses increases very greatly, and unless considerable care be used to adjust the speed of stirring to the viscosity the wave of glass which accompanies the stirring-tube is likely to fold over and entrap air. That this happens is not a matter of conjecture; such entrapped bubbles have been actually observed as they were swept downward into the melt. The remedy is to see that the stirring-tube does not travel so fast as to push a high ridge of glass in front of it. Further on in this article the stirring process will be described and data on the speed of movement for different types of glasses will be given. By using care bubbles of this kind may be avoided. Before the danger of entrapping air in this manner had been fully realized, a pot of borosilicate crown had, in one rather striking instance, been carried to a lower temperature (and greater viscosity) than usual. As a result the glass contained innumerable bubbles, whereas ordinarily this type of glass was almost perfectly free of them.

A third source of mechanical bubbles is a leaky stirring-rod. The stirring-rod is a water-cooled contrivance, at whose furnace end a reducing, right-angled elbow receives a hollow iron pin, which fits into the orifice left for the purpose in the upper end of the clay stirring-tubes (see Fig. 2). We have found that the joint made by screwing the pin into the elbow may appear water-tight when tested in the cold, but that during use in the furnace there may be a slow leak, probably due to unequal expansion. The evidence of this is twofold. First, we had the very direct evidence that when the pin was lifted out of the tube at the end of stirring a little dampness or even a drop or two of water has been observed on it. Second, while the stirring of the metal was being watched, a rather large bubble had been observed to rise to the surface of the melt occasionally, very close to the

stirring-tube. This had apparently been formed in the following manner: A drop of water had collected on the pin and had finally dropped down into the tube. There it had been vaporized so suddenly that some of the vapor had been forced out through the pores of the tube into the melt. If the melt were at a high temperature and of an intrinsically fluid nature the vapor rose to the surface, but if not it was distributed through the melt. An effective remedy for this is to set the pin in the elbow with a litharge-glycerine cement.[1]

In addition to the bubbles entrapped by the various methods which have been described it appears that there are bubbles of quite different origin. They seem to consist of gas which has been in solution in the melt at a high temperature and has been evolved on cooling. We have found that in some cases, after care had been taken to eliminate all the possibilities mentioned and the glass had become free from bubbles during fining, nevertheless, in the subsequent cooling during stirring, bubbles had reappeared and had persisted to the end. Such a phenomenon of greater solubility at higher temperatures is rather exceptional and is not, strictly speaking, one in which we have a simple solution of gas in a liquid. There is probably of necessity a chemical reaction between the gas and the constituents of the liquid. This reaction must be endothermic, for it is only under this condition that the solubility of a gas is increased on heating and decreased on cooling.

Our experience indicates that not all types of glass are affected by bubbles of this kind, and not any type under all conditions, but we are not able to state definitely what the conditions are which cause them to appear. We suspect rather strongly that those crown glasses which contain barium in small to moderate amounts are especially prone to dissolve gas and later evolve it as bubbles. Therefore, until more certain evidence is obtained,

[1] Made by adding litharge to glycerine and working it to a paste with a spatula. A very little water may be added to the glycerine. The time required for setting depends upon the fineness of grain of the litharge, amount of water, and proportion of litharge to glycerine. See a paper by H. E. Merwin in *Jour. Ind. Eng. Chem.*, **9**, 390 (1917).

we would look upon barium as a trouble-maker in such glasses and avoid its use where possible.

Still another class of bubbles, which may be termed vacuum bubbles, appear under certain exceptional circumstances. If a pot of glass be cooled quickly a rigid crust forms over the surface while the interior is still hot. Then when the interior cools and endeavors to contract it is held by the rigidity of the crust. If the glass contain bubbles of even the most minute dimensions (and probably they are always present), they act as points of weakness, and the glass contracts in every direction from them. Such a glass may, after cooling, appear full of large bubbles, especially in the last-cooled portions, but if it be carefully heated to a softening temperature the bubbles collapse until they are invisible or nearly so. If the proper procedure is followed, bubbles of this kind should never appear in our regular melts. They may be expected, however, in small experimental melts, where no special effort is made to have the glass cool properly.

The Function of Arsenic.

Closely associated with questions of the origin and elimination of bubbles is the matter of the use of arsenic in glass-making.

Arsenic in small quantities in the form of As_2O_3 is almost universally used in optical glass and very commonly used in other glasses. It is said to cause the melt to fine better and to make the glass more brilliant. The manner in which it accomplishes these results is rather uncertain. Allen and Zies,[1] in a recent article, have discussed the matter in the light of the latest information and have indicated the manner in which the oxides of arsenic may function in causing a boil and sweeping out the small bubbles, whose rate of ascent when unaided may be almost negligible.[2] We may amplify their idea slightly and add the suggestion that bubbles of arsenic vapors may not only gather up gases which have already been set free as bubbles, but that they may collect *potential* bubbles; that is, in the relation of these

[1] E. T. Allen and E. G. Zies, "The Condition of Arsenic in Glass and Its Rôle in Glass-making," *J. Am. Ceram. Soc.*, **1**, 787 (1918).

[2] Raymond M. Howe, "Principles Controlling the Formation and Removal of Bubbles in Molten Glass," *Trans. Am. Ceram. Soc.*, **19**, 201 (1917).

vapors to other substances which tend to be evolved slowly because of the hydrostatic pressure and surface tension[1] to which they are subjected, they may act as vacuum chambers into which these substances may evaporate at a much more rapid rate.[2] Although our knowledge of the manner in which arsenic acts upon the melt is rather deficient, the addition of arsenic is generally looked upon as being beneficial, and we may well continue its use. The amount added is always small. If an excess be used it has a tendency to produce a milky or opalescent glass. Zschimmer's tables show that at the Jena works the amount of As_2O_3 ordinarily put into the batch is about 0.3 per cent of the weight of the glass. In our own practice we generally used about the same amount or a little more.[3]

Leakage.—During the whole period of making a pot of glass a watch should be kept to see that the pot has not begun to leak. On account of the relatively corrosive properties of many optical glasses the danger is much greater with them than with plate glass, tableware, window glass, and batches of similar nature. The means which we found most effective in reducing leakage losses was to see that the temperature was kept uniform and not allowed to rise thirty or forty degrees beyond the established point as might happen through carelessness. The inauguration of a reliable system of temperature-control was attended by a remarkable difference in respect to losses of that kind. Inasmuch as the likelihood of leakage is greater with optical glasses,

[1] Raymond M. Howe, *Op. cit.* Howe shows that surface tension is probably a very effective force in restraining the growth of bubbles.

[2] According to the laws of gases a bubble filled with one gas represents, to all intents and purposes, a vacuum for a second gas. This is closely related to what is known as Dalton's law. See E. W. Washburn, "Principles of Physical Chemistry" (1915), p. 26, or W. Nernst, "Theoretical Chemistry," Fourth English Edition (1916), p. 39.

[3] The question of the use and function of arsenic requires further investigation. At Charleroi the preference was given to the use of considerably larger quantities of arsenic than 0.3 per cent, especially in the crown glasses. This practice was based on that of plate-glass making and the greater quantity was supposed to help fining. On the other hand, arsenic has been left out altogether in some instances at Hamburg, and the metal appeared to fine equally well.

precautions against it must be more strictly observed. In addition to keeping the temperature uniform other measures which should be carried out may be summarized as follows:

We must see that only best-quality pots are used; that they do not become damp or subjected to extremely cold temperatures while in storage; that they are handled gently while in the unburned condition; that the preliminary heating in the arch is done slowly and evenly and is carried to a bright cherry-red; that they are examined in the transfer from arch to furnace; that they are heated in the furnace to fining temperature or higher before filling is begun; that cullet is charged and allowed to soak into the pores before raw batch is added; and that for especially corrosive glasses the pot used be of a special clay mixture designed to withstand corrosion. With these precautions regularly enforced the number of pots that will fail will be extremely small.

Skimming and Stirring.—In running on a 48-hour schedule the melt or metal should be fine or plain by the evening of the day following that on which filling began. In fact, the fining may have reached a satisfactory stage before this, but unless we are endeavoring to hurry the process the melt may be allowed to stand quietly until about 7 P.M. Then, if it seems necessary, the surface should be skimmed. The indications are the presence of a scum of froth or stones on the surface. The stopper of the hole in the tuille is taken down and the skimmer inserted. This is a long-handled iron tool at whose further end a skimming blade is joined at right angles to the handle. The operation must be performed in such a fashion that the blade passes over the surface of the melt with a smooth, even stroke without bringing about such swirls or other disturbances as would cause surface material to be carried down into the melt, and at the end of the stroke the material must be gathered up on the tool and brought out. Some knack is required to perform these operations properly. If they are improperly performed surface material is forced down into the metal and does not soon rise again.

Care should be taken not to remove more glass than necessary. There has been gravitative segregation or liquation dur-

ing melting, and the composition of the surface layer does not represent the average composition of the melt. Therefore the greater the quantity of glass that is removed the more the average composition of the whole is changed. It would be better if we could avoid skimming altogether, but where it is necessary to skim, as is occasionally the case, we should see to it that an unnecessary quantity of glass is not removed. Some workmen will fall into this error through carelessness and some from excess of zeal.

After the metal has been skimmed it is allowed to rest for an hour and then the first hand-stirring is performed. Prior to this, however, certain preparations must have been made in the way of getting stirring-tubes ready. The stirring-tube is a thick-walled tube of clay whose length is about equal to the depth of the pot. For a pot 27 inches in depth we should have the tube about 26 inches long when dried and burned, keeping in mind that an appreciable shrinkage results from the latter operations. The outside diameter at top should be about 4 inches for a tube of this length, and should decrease to 3 or $3^1/_2$ inches at the lower end.[1] At the upper end there is a circular flange about an inch thick, which projects about an inch from the main body of the tube, and is used for holding the tube when the stirring-rod is withdrawn. After a tube has been fashioned it is set aside to dry for a week or two. Then while still soft (though firm) the central hole is modified in shape a little at the upper end. By means of a coarse file the circular section is changed to that of a square which is tangent to the circle, for a length of about four inches. The purpose is to have the shape of the hole conform to the shape of the iron holding-pin of the stirring-rod which enters it. This pin is square in section for about this distance at its upper part (where it joins the main rod) and is circular below this for a length of, say, three inches. The exact value of these dimensions is not important, except that the dimensions of the hole in the clay tube must conform to those of the pin. The purpose of the pin is to hold the tube in proper

[1] The thickness of tube used varies somewhat at different plants, and some latitude is allowable. The requirements are that the tube should be large enough to be an effective stirrer without being unwieldy.

position, and the square section of a portion of it prevents rotation during stirring.[1]

After the tube has been dried and the central hole shaped in the manner described, the tube must be burned. About an hour before one is to be used it is transferred from the salamander or from the arch in which it has been heating to the furnace and laid on the fire-wall to receive its final heating. A few minutes before stirring begins the tube is lifted off the fire-wall with an iron hook and gradually and carefully lowered into the melt and left floating there for a few minutes in an inclined position, with the flange at the upper end hooked over the lip of the pot. In a short time any bubbles that may have been given off will have risen to the surface. Then the water-cooled iron stirring-rod is introduced into the furnace, its pin is inserted into the hole in the tube, and stirring begins.

Just outside of the furnace the stirring-rod rests on a small grooved wheel[2] which turns on a horizontal axis primarily and whose shank is revolvable in a vertical socket secondarily. This permits the farther end of the rod to move continuously around a circle. Near the handles which the workman grasps the principal weight of the rod may conveniently be taken up by an iron hook attached to a cord, which passes around overhead pulleys to a counterweight. The hose connections are made near the handle and a constant stream of water is kept running through. As the water emerges from the outlet hose it should be appreciably warm but not hot.

The hand-stirring is carried on for 15 minutes at a time, at the rate of 24–28 revolutions per minute. The movement is a

[1] This description applies to the practice at two of the plants. At the third the construction of the stirring-rod is such that the pin which enters the tube is simply the terminal part of the main rod bent at a right angle and drawn down to a smaller diameter. Its cross-section is circular throughout. This construction is simpler, but unless very careful blacksmithing work is done the pin is likely not to fit closely in the tube and the tube may wabble during stirring.

[2] This wheel is supported on a length of channel-iron which passes horizontally across the front of the tuille and is, in turn, bolted rigidly (though temporarily) to the buck-staves of the furnace frame. The device is kept in position only during the period of hand-stirring.

combination of a circular and a vertical motion. At one portion of the circle the end of the tube is brought as near to the bottom of the pot as can conveniently be done without scraping, and at another portion it is lifted several inches. The chief purpose is to produce a thorough mixture of the metal; therefore in medium and heavy flints the stirring should be especially vigorous.

A proof taken after the stirring is over will often show that a quantity of bubbles have been detached from the pot-walls or set free from solution in the glass and brought to the surface. They should be of rather large size and should escape easily from the melt.

After the 15-minute stirring is finished the water-cooled stirring-rod is withdrawn from the furnace. The tube is left floating in the melt in the same position as when it was first introduced. Hand-stirring is repeated during the night at two-hour intervals. At about seven o'clock the next morning stirring by machine is begun. The stirring-machine (shown in Fig. 2) is an electric motor-driven device so constructed as to reproduce the circular and up-and-down motions described under hand-stirring, but to perform the operations in a smooth, even manner while rigidly following a prescribed course, and to continue it for hours. At one time or another several types of machines have been tried at the different plants, and from a comparison of their performances it becomes quite evident what requirements such a machine should possess.

The machine should be easily movable from place to place and should be capable of being quickly removed when stirring is over; therefore, it is provided with traveling wheels with offset sockets on the plan of the castors of a chair. When the machine is in position in front of the furnace the weight is taken off the wheels by elevating screw-posts. By means of these posts one may also adjust the height a trifle, but the principal adjustments for height should be elsewhere. It is essential to be able to change the speed of operation, and for this purpose we may either use a constant-speed motor in connection with step pulleys, or we may vary the speed of the motor by a rheostat and running-box. The latter arrangement is more expensive but considerably better. In any case we should be able to vary

the speed of stirring from about 28 to 4 or 5 revolutions per minute, the variation being either continuous or in not less than four steps. The horizontal rotating arm to which the outer end of the stirring-rod is attached and by which a circular motion is given to both the outer and the inner (or furnace) ends of the rod, is mounted on a vertical axle driven by bevel-gears from the pulley-shaft. In order to attach the stirring-rod to the arm the

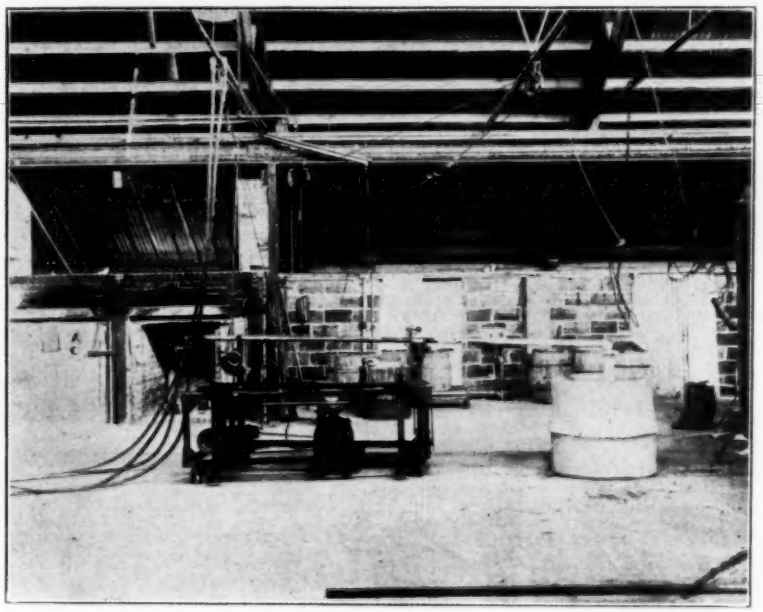


FIG. 2.—Stirring machine set up to show its position with relation to the pot.

latter is provided with a slot which receives a corresponding lug on the stirring-rod. A stout pin passes through the two and is held by a split cotter. This arrangement permits the rod to be mounted or dismounted in a moment. The height of the arm should be adjustable, and to effect this its attachment to the vertical axle which turns it is by means of a movable collar which may be slipped along the axle and held at the desired height by a set-screw.

The stirring-rod is supported at the middle on a grooved wheel similar to that used for the same purpose in hand-stirring, but here the shank (pedestal) of the wheel is extended to form a long rod or post, which passes through bearing-boxes on the framework of the stirring-machine and is attached to the mechanism in such a manner that an up-and-down motion may be imparted to the post and wheel by a crank-drive. The result of these various mechanisms is that the outer end of the stirring-rod is carried around a horizontal circle, the median portion is given a vertical motion, and the inner end combines the two. Strictly speaking, the horizontal component of the motion of the inner end is not circular. The curve described is an oval, which, however, does not differ greatly from a circle. The height of the wheel-post may be varied in a fashion similar to that described for the rotating arm. Likewise the length of stroke of the post may be varied, although this is hardly necessary. Some machines which we used were provided with means for varying the vertical stroke, but in practice they were left set at a stroke of about $2^1/_4$ inches. By all means, however, it should be possible to take off the vertical motion altogether with little trouble or delay. It is essential also that the effective radius of sweep of the horizontally rotating arm may be changed easily by a screw-feed. During most of the period of stirring the radius of the stirring-circle is left without change, but as the glass cools and stiffens in the final stages of stirring the radius of the stirring circle is cut down. The vertical motion of the supporting post should be related to the horizontal motion of the rotating arm in such a way that they do not synchronize but that the uppermost (or lowermost) part of the stroke advances a certain amount each time on the horizontal circle. A satisfactory arrangement is to have one complete stroke (from upper limit to lower limit and back) in about $1^1/_4$ revolutions. The whole machine should be rigid in construction and not likely to get out of order, and the settings and changes required for proper stirring should be easily effected.

When the machine is first set in motion the radius of the stirring-circle is cut down to the lowest limit so that the clay tube makes only a very small circle around the center of the pot. Then the circle is increased in size until it approaches the outer cir-

cumference. Care should be taken, however, to see that the clay tube does not approach the pot-walls so closely that it touches at any point or does not pull off the skin of glass adhering to the walls. For a pot whose diameter at bottom equals 25 inches we have found that a stirring-circle of 7 inches radius is a quite satisfactory maximum. As the stirring-tube has a radius of about two inches the circle passed through by the outer portions of the tube has a diameter of 18 inches under such conditions. At the speed with which the machine is driven all the glass in the pot is effectively agitated and mixed when the tube describes such a circle.

In setting the tube for height the endeavor is made to have the bottom of the tube come near enough to the bottom of the pot so that no layer of glass is left unstirred, but to avoid the danger of letting the tube touch the bottom. To accomplish this a clearance of about two inches between the end of the tube and the bottom of the pot should be allowed.

It is only with glasses which have a strong tendency to form a heavy bottom layer that a vertical motion is given to the tube in machine-stirring. Therefore, in general, the vertical motion is used only with medium and heavy flints. For these the vertical stroke of the supporting post may be made $2-2^1/_4$ inches. As this motion is imparted to the stirring-rod at midway of its length, the far end of the rod with its attached tube is given a vertical motion of $4-4^1/_2$ inches. It has been found in some cases that even with dense flints ($n_D = 1.650$) the vertical motion may be dispensed with. In these cases large quantities of cullet (40 to 50 per cent) were used, and under such circumstances there is much less likelihood of the settling of a heavy layer to the bottom.

The viscosity of different glasses varies considerably at the stirring temperature, and the speed of stirring likewise varies to some degree. Of the common glasses dense flint stands at one extreme and light crown at the other. A speed which has been found to work well with flints is 18 revolutions per minute with a stirring circle of 7 inches radius. This gives a speed of 792 inches or 66 feet per minute as the rate of horizontal travel of the stirring-tube through the glass. In addition there is, with

flints, a vertical motion imparted to the tube, as already stated. In the case of light crown and similar glasses the danger of stirring bubbles into the melt makes it desirable to run more slowly Therefore a speed of about 45 feet per minute has been used. For borosilicate crown the speed has been about the same as for flints.

Up to the time that stirring by machine has been begun the temperature has been kept up to 1400° C or thereabouts (varying somewhat with the type of glass). During the progress of machine-stirring the stopper is out continuously and the furnace naturally cools somewhat. This is quite allowable at this stage, but the drop should not exceed 75–80° C.

Machine-stirring is continued without change for four or five hours. Then the gas is shut off, the air-inlet to the regenerative chambers is closed, the stack-damper lowered, and the butterfly-valve swung to the intermediate position. The metal has been thoroughly mixed and now it is allowed to cool and stiffen. Stirring must be continued, however, for the sources of inhomogeneity are still active. The principal source is doubtless the bottom and walls of the pot, by whose solution foreign material is constantly supplied; but another source is the upper surface of the metal, from which selective volatilization has been going on. The actual change in mass composition due to these gains and losses is probably so small that when mixture is complete and uniform the optical properties are not greatly affected thereby. It is not, indeed, the change in total composition which gives us concern, but the likelihood that material of different composition will be only imperfectly distributed through the mass. It is astonishing to find what slight differences in refractive index are exhibited by cords or striae which are so pronounced as to stand out in plain relief. When the difference is only in the third place of decimals a cord is quite perceptible. This means that the difference in composition is so small that diffusion is not a very effective factor and must be mechanically aided. The principle on which stirring effects its results is that these heterogeneous portions of the melt are mechanically spread out to such a degree that they present great surfaces of contact per unit of volume and only a short time is required for diffusion to overcome all

differences that exist. From the time that the gas is turned off the procedure followed is directed chiefly toward eliminating the conditions which permit striae to form. To effect this the heterogeneous material must be thoroughly distributed through the mass almost at the source from which it proceeds; at the same time conditions must be so changed that the tendency toward solution of the pot and volatilization from the surface is decreased, while the mechanical obstacles presented by viscosity to the movement of convection-currents are gradually becoming greater. These objects are attained more or less perfectly by continuing stirring as vigorously as may be without running the risk of causing air to be entrapped, while cooling the melt to a temperature which has been found by experience to be suitable. This temperature varies widely with different glasses, and the time required for cooling varies accordingly.

If one watches the stirring while the temperature is dropping one sees that the ridge of glass pushed ahead of the stirring-tube gradually becomes more prominent and if no change in the speed of stirring were made the ridge would, before long, reach a height of several inches. Obviously it is necessary to decrease the speed as the glass thickens. The vertical motion of the tube is unnecessary after the fire has been turned off and may be dispensed with at that time, and soon it is advisable to lessen the speed of angular rotation and to diminish the size of the stirring-circle. The proper amount of diminution is judged by the appearance that the passage of the tube through the glass presents, and is a matter that can hardly be described but must be learned by experience. However, temperature charts and records of operations during some typical runs are here presented, which may serve as a basis of comparison. The information is taken without modification from records made during actual operations. Where it is believed that the procedure might have been improved at some point a memorandum is introduced. The radii of stirring circles given are those measured at the outer end of the stirring-rod, but as the point of support or pivot of angular movement of the rod is about midway of its length the same figures apply without much modification to the inner end.

EXAMPLES OF PROCEDURE IN STIRRING.

(See also Charts 1–4.)

No. 1. Medium Flint. (n_D = 1.605, ν = 37.6.)

Pot 25 inches in inside diameter at bottom, 27 inches deep.

8 : 03 A.M. Started stirring machine at 13 rev. per min. Radius of stirring circle = $6^1/_8$ inches. Vertical motion = $4^1/_4$ inches. (Mem.: A stirring circle of greater radius would have been preferable.)

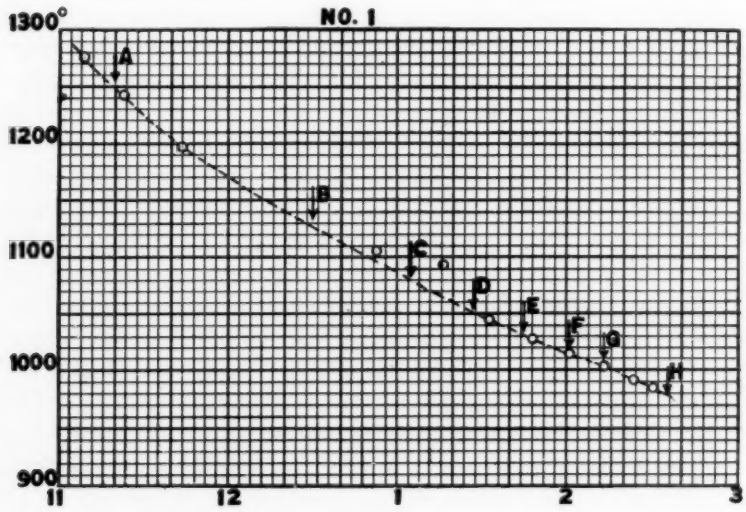
8 : 07 A.M. Changed speed to 18 rev. per min.

11 : 00 A.M. Shut off gas, air, etc.

11 : 09 A.M. Temp. (sighting on surface of glass) = 1276° C.

11 : 20 A.M. (A) Took off vertical motion.

11 : 23 A.M. Temp. = 1241° C.



11 : 44 A.M. Temp. = 1197° C.

12 : 30 P.M. (B) Radius of stirring circle reduced to $5^1/_8$ inches. (Mem.: It might well have been kept a little larger.)

12 : 53 P.M. Temp. = 1104° C.

1 : 05 P.M. (C) Changed speed from 18 to 13 rev. per min.

1 : 17 P.M. Temp. = 1092° C.

1 : 27 P.M. (D) Radius of stirring circle reduced to 4 inches.

1 : 33 P.M. Temp. = 1044° C.

1 : 45 P.M. (E) Reduced radius of stirring circle to $3^1/_4$ inches.

1 : 48 P.M. Temp. = 1028° C.

2 : 01 P.M. (F) Temp. = 1013° C. Reduced radius of stirring circle lightly.

2 : 13 P.M. (G) Temp. = 1003° C. Radius of stirring circle now about $1^1/_2$ inches.

2 : 23 P.M. Temp. = 990° C.

2 : 30 P.M. Temp. = 984° C.

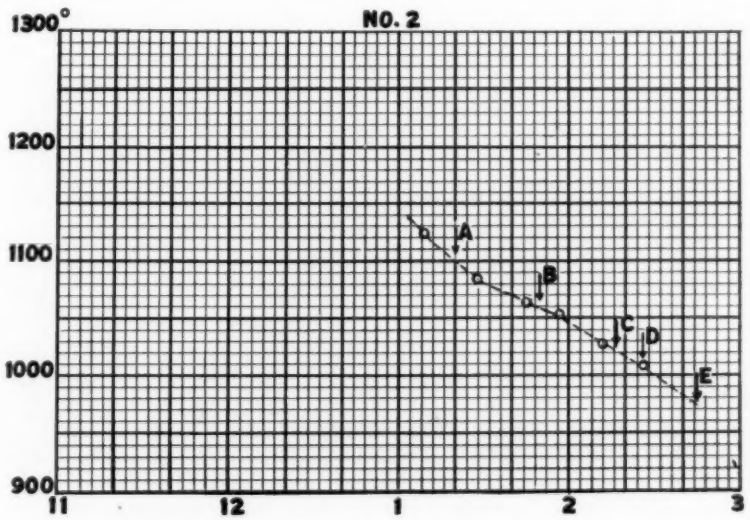
2 : 35 P.M. (H) Stirring stopped. Extrapolation gives temperature of 975° C.

2 : 40 P.M. Pot out.

(Mem.: A temperature of 950° C at time of stoppage of stirring would have been preferable for this type of glass.)

No. 2. Baryta Flint. (n_D = 1.619, ν = 37.6.)

Pot 20 inches in inside diameter at bottom, 25 inches deep.



8 : 15 A.M. Started stirring machine at 13 rev. per min.; soon afterward changed to 26 rev. per min. Vertical motion $4^1/_2$ inches. Radius of stirring circle = 5 inches.

11 : 50 A.M. Shut off gas, air, etc. Changed speed to 18 rev. per min. Took off vertical motion.

1 : 09 P.M. Temp. = 1122° C.

1 : 20 P.M. (A) Changed speed to 13 rev. per min.

1 : 28 P.M. Temp. = 1084° C.

1 : 45 P.M. Temp. = 1061° C.

1 : 50 P.M. (B) Reduced radius of stirring circle to 4 inches.

1 : 57 P.M. Temp. = 1053° C.

2 : 12 P.M. Temp. = 1028° C.

2 : 17 P.M. (C) Radius of stirring circle reduced to 3 inches.

2 : 26 P.M. (D) Temp. = 1007° C. Radius of stirring circle reduced again.

2 : 45 P.M. (E) Stirring stopped. Extrapolated temperature = 975° C.

2 : 50 P.M. Pot out.

No. 3. Light Crown. (n_D = 1.516, ν = 60.0.)

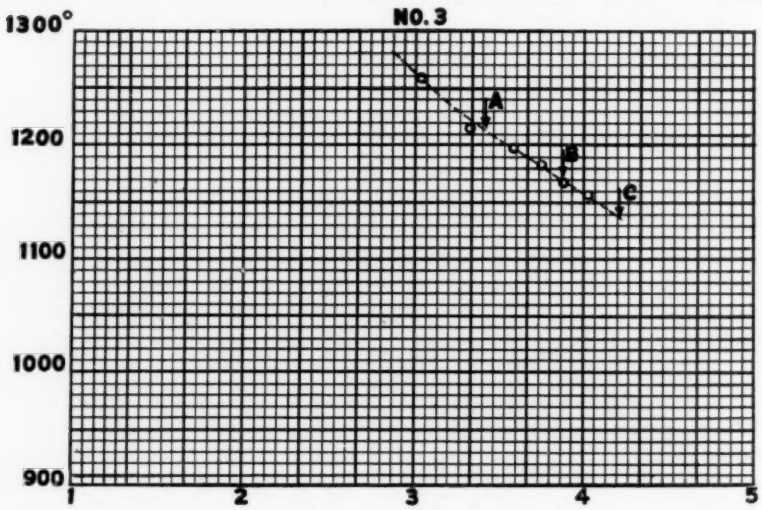
Pot 25 inches in inside diameter at bottom, 27 inches deep.

8 : 03 A.M. Started stirring machine at 13 rev. per min. No vertical motion. Radius of stirring circle = $6^1/_2$ inches.

8 : 25 A.M. Changed speed from 13 to 18 rev. per min.

8 : 55 A.M. Changed speed from 18 to 13 rev. per min.

9 : 50 A.M. Reduced radius of stirring circle to about 5 inches. (Mem.: A proof taken just before this had shown quite numerous bubbles; therefore,



the speed of travel was reduced to avoid the danger of stirring air into the metal.)

2 : 35 P.M. Shut off gas, air, etc.

3 : 02 P.M. Temp. = 1259° C.

3 : 19 P.M. Temp. = 1214° C.

3 : 25 P.M. (A) Radius of stirring-circle reduced to 4 inches.

3 : 35 P.M. Temp. = 1197° C.

3 : 45 P.M. Temp. = 1182° C.

3 : 53 P.M. (B) Temp. = 1168° C. Radius of stirring-circle = $2^1/_2$ inches.

4 : 02 P.M. Temp. = 1156° C.

4 : 13 P.M. (C) Stirring stopped. Extrapolated temp. = 1138° C.

4 : 18 P.M. Pot out.

No. 4. Borosilicate Crown. (n_D = 1.511, ν = 64.1.)

Pot 25 inches in inside diameter at bottom, 27 inches deep.

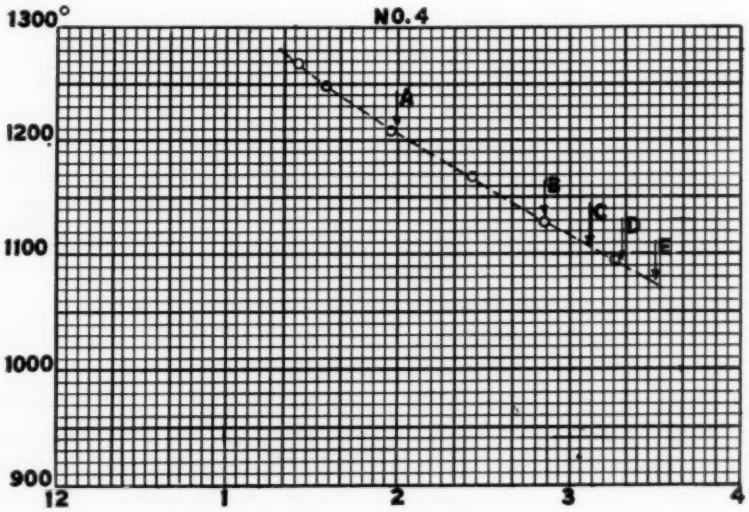
8 : 10 A.M. Started stirring-machine at 13 rev. per min. No vertical motion. Radius of stirring circle = $6\frac{1}{2}$ inches. Changed in a few minutes to 18 rev. per min.

1 : 15 P.M. Shut off gas, air, etc.

1 : 25 P.M. Temp. = 1266° C.

1 : 35 P.M. Temp. = 1247° C.

1 : 58 P.M. Temp. = 1208° C.



2 : 00 P.M. (A) Changed speed of stirring to 13 rev. per min.

2 : 26 P.M. Temp. = 1166° C.

2 : 51 P.M. (B) Temp. = 1127° C. Reduced radius of stirring-circle to 5 inches.

3 : 07 P.M. (C) Reduced radius of stirring-circle to 4 inches.

3 : 16 P.M. Temp. = 1095° C.

3 : 18 P.M. (D) Reduced radius of stirring-circle.

3 : 30 P.M. (E) Stirring stopped. Extrapolated temperature = 1075° C. (Mem.: This is rather high. 1050° C would have been preferable.)

3 : 35 P.M. Pot out.

Probably the examples given may be taken as fairly representative of the procedure to be followed during cooling and stiffening, but in making application to other cases caution must be used because of the fact that a type of glass having certain optical

properties may vary in chemical composition, and the treatment necessary will be closely related to the latter. For instance, it was found at Hamburg that the light flint made there should be cooled to 925° C before stirring was stopped. A glass of very similar optical properties but of somewhat different chemical composition (lower in alkalis), made at Charleroi, was removed from the furnace at a temperature higher by 100°.

There is much room for the personal equation to enter as an important factor in making measurements with the optical pyrometer on a pot of cooling glass. Different observers differ considerably in their ability to match the luminosity of the filament with that of the object sighted upon. Moreover, the angle at which the pyrometer is directed upon the surface of the glass is probably of some importance (because of surface reflections); and also, in the later stages of cooling, there actually are marked differences of temperature at different parts of the surface. At high temperatures the conditions of temperature-measurement are probably almost ideal for the employment of an optical pyrometer, as the light emanates from a self-luminous, transparent source within the mass, and the agreement with black-body conditions should be practically perfect[1]. Moreover, at this stage the temperature-differences in different regions are small. At a later stage, however, it is easy to perceive that the swirls of liquid brought to the surface by the passage of the stirring-tube are hotter than the surrounding material. Then the measurement of temperature becomes, to a certain degree, an empirical opera-

[1] This is true unless glass at a high temperature possesses the property of luminescence; that is, that it emits light whose intensity does not correspond to that which a black body would emit at the same temperature. This is a possibility which must be taken into account until our data on the matter are more complete. At present the probabilities seem to be against it.

If one tries to look into a pot of glass which has just been removed from the furnace and has a temperature somewhere between 950° and 1100°, the impression produced is not that of looking deeply into a transparent mass but of looking into something which has the appearance of a milky, luminous haze. The explanation is probably this: that a body whose luminosity is due to its temperature tends to cut off light of any wave-length which it itself is sending out. Therefore, in such a pot of glass, the cool crust is transparent to the light proceeding from the glowing mass below, but the latter is (within a certain distance) opaque to its own radiations.

tion, and one must decide where he shall sight the pyrometer. The temperatures which have been given and others which will appear in a similar connection later refer to the hottest parts of the melt, close to the stirring-tube.

The temperature at which stirring is stopped and the pot set out is a matter of the greatest importance. Upon this principally will depend whether the glass is badly affected by striae or not. There are probably other factors to which, at times, striae are due. One of these is failure to break up and diffuse by vigorous stirring the layer of heavy glass which has segregated and sunk to the bottom of the pot, especially in dense flints. The formation of this layer has been referred to a number of times, and attention has been called to the procedure to be followed to eliminate it. Striae may be caused also by setting the pot, after removal from the furnace, into an arch that is too hot, thus causing convection-currents to be set in motion. This also may be quite easily avoided by proper attention. It is a somewhat more delicate and difficult matter to have stirring stopped at just the right moment and have the pot brought out promptly.

On a previous page the principal source of striae has been traced to dissolved pot material. If stirring be stopped at too high a temperature, this solvent action is still going on quite vigorously, and the viscosity of the metal has not yet become sufficient to oppose much resistance to the rise of convection-currents. The hottest part of the pot is the bottom, for during cooling the siege has been protected by the pot itself. Therefore, during the few minutes which elapse after stirring has stopped and before the pot is lifted from the siege convection-currents tend to be set in motion from this source. For this reason the metal must be cooled to a point where this tendency is small. Moreover, no unnecessary delay should be allowed to occur between the stoppage of stirring and the removal of the pot. It might seem that cooling and stirring should continue to a point where the danger arising from convection-currents is obviously past, but this may not be done. There would be a probability of stirring air into the glass under such a procedure, and also a probability of dragging off into the melt the skin of glass lying next to the sides and bottom of the pot. This is a thin layer whose composition

is affected by solution of pot-material, and which, under ordinary circumstances, adheres closely to the pot, but may be pulled off if the stirring be continued until the glass is very stiff, and then gives rise to heavy cords. For these reasons the optimum temperatures for the cessation of stirring must be determined within rather narrow limits. Especially is this true with medium and heavy flints, whose compositions and optical constants differ greatly from those of the materials arising from pot-solution. With ordinary crown and borosilicate crown there is much less difference in this respect and more leeway is permissible.

In order to insure that the pot is set out at the proper temperature the fall of temperature is followed with the optical pyrometer during the later stages of stirring, and a few minutes before the end an extrapolation of the course of the temperature-time curve is made to the desired point. Following is given a list of temperatures for the cessation of stirring which have been found applicable to a number of common types of glass. In making use of this table the caution must be kept in mind that each figure applies to a glass of a certain chemical composition and not to a glass of a certain optical type. Moreover, it is not unlikely that furnace construction affects the rate of cooling, and perhaps other factors of an unknown nature may change the figures slightly. They may be taken at least, as fairly definite starting-points for experiment, and it is believed that, on the whole, not much change will be found necessary.

TABLE 1.

TEMPERATURES AT WHICH TO CEASE STIRRING.

(The compositions of the glasses to which these figures apply are given in Table 2.)

Borosilicate crown	1050° C
Light crown	1150° C
Baryta flint	980° C
Medium flint	950° C
Light flint	925° C
Barium crown	1025° C

During the cooling and stiffening of the glass the speed of stirring has been reduced and the size of the stirring-circle has been diminished, until, in the last stages, the stirring-tube re-

volves slowly around a small circle in the center. Then, at a moment which has been determined some time before, the electric current is shut off from the stirring-machine and preparations are made to take the pot out. By all means this should be done quickly, in order to prevent the rise of convection-currents from the bottom, and each workman who is to take part should know what his duties are. The first operation is to move the stirring-tube from the center over to the left side of the pot. This is done, before the stirring-tube is disengaged from the rod, by swinging the rod outward from the center by means of the screw-feed. This imparts a smooth, even motion to the tube and obviates the likelihood of its digging into or otherwise disturbing the layer of glass close to the bottom of the pot. When the tube has been brought near the side it is held in place momentarily by a fork-like tool made for the purpose, while the stirring-rod is lifted out, withdrawn from the furnace, and laid aside. Then a rod of round iron, one inch in diameter, bent in the form of an inverted U, is dropped down in such a manner that one leg of the U enters the central hole in the tube and the other leg drops over the outside of the pot. The distance between the legs is such that when the hook is in this position the stirring-tube is held close to the pot-wall. One leg of the U should be about 14 inches long and the other 10 when used with a pot whose height from the shoulder to the rim equals 16 inches. The shorter leg is dropped into the tube. The weight of the hook keeps the stirring-tube in a nearly upright position.[1] The stirring-machine is now pushed to one side and the tuille is slightly lifted. By means of a heavy bar with a chisel bit a small hole is driven between the bottom of the pot and the siege (large enough to get the edge of the bar under the pot), a block of iron is laid on the siege as a fulcrum, and the pot is pried loose. The loosening should not be by sudden jolts on the outer end of the bar but by a steadily exerted force. In that way the giving-way of the gluey material which holds the pot will be gradual and will not lead to a sudden agitation of the glass. The tuille is now lifted high, the pot-wagon is run in and the pot

[1] An alternative method is to lift the tube out of the glass altogether. This seems inherently more likely to produce disturbances of a kind that will cause striae, and practical results seem to confirm this inference.

is clasped in its tongs. Counterweights nearly balancing the weight of pot and contents are lifted onto the outer pole of the wagon, the pot is raised quickly but carefully, brought out, and deposited on a tile. The time which elapses from the moment that stirring stops until the pot rests on the tile should seldom exceed five minutes, and when the working force is well organized and matters proceed without a hitch, it will probably not exceed

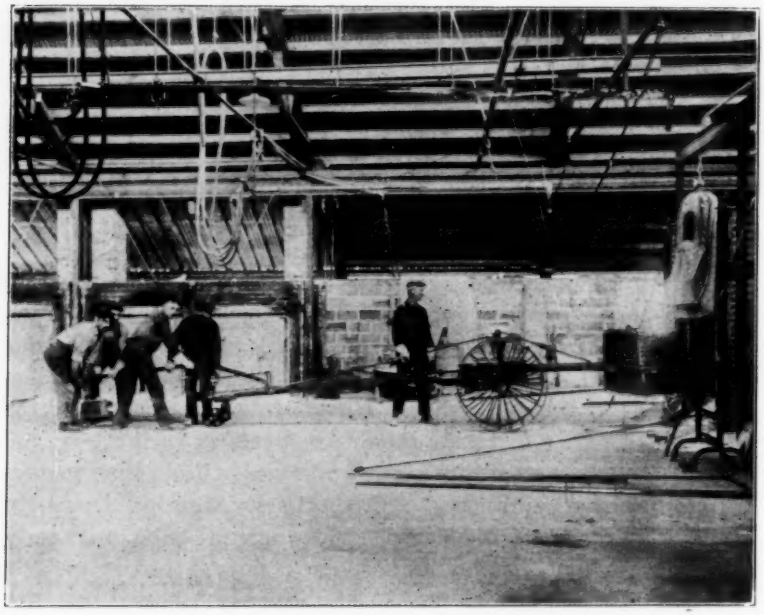


FIG. 3.—Removing pot of glass from the furnace.

three. Fig. 3 illustrates the operation at the moment that the pot is being withdrawn from the furnace.

The pot is left resting on the tile while the siege is got ready for the next run and a new pot is carried from the hot arch and set in the furnace. Then the pot just finished is placed in the arch left vacant. This procedure, however, may be modified. For instance, we found at one time that a certain lot of pots, which were very good in most respects, showed the bad feature of tending to crack while exposed to the cold air, and in one instance a

large section of pot-wall fell out and allowed nearly half the contents of the pot to escape. For these pots we adopted the practice of having an empty arch heated and ready, into which the pot of glass was carried directly from the furnace. The pot to

TABLE 2.
BATCH COMPOSITIONS.

	Medium Flint $n_D = 1.605$ $\nu = 37.6.$	Baryta Flint $n_D = 1.619$ $\nu = 37.6.$	Light Crown $n_D = 1.516$ $\nu = 60.0.$	Boro-silicate Crown $n_D = 1.511$ $\nu = 64.1.$	Light Flint $n_D = 1.580$ $\nu = 41.1.$	Barium Crown $n_D = 1.570$ $\nu = 57.0.$	Dense Flint $n_D = 1.640$ $\nu = 34.6.$
Sand	100	100	100	100	100	100	100
Pb_3O_4 ·	90.50	89.10	....	....	68.06	....	124.10
or	or	or			or		or
PbO	88.40	87.05	...	....	66.46	....	121.20
K_2CO_3 (anhydr.)	10.30	21.30	10.00	15.60	9.44	5.20	5.28
KNO_3	7.81	9.63	12.39	14.00	8.77	11.30	10.30
Na_2CO_3	15.40	....	19.30	18.15	20.51	15.09	16.40
$BaCO_3$	....	19.00	4.69	....	....	75.28	....
ZnO	....	6.95	....	....	....	18.25	....
H_3BO_3	....	....	....	21.00	....	13.60	....
$CaCO_3$	....	....	20.00	5.00	....	....	....
Al_2O_3	....	....	....	....	....	2.07	....
As_2O_3	0.60	0.60	1.00	0.40	0.74	0.61	0.72
Percentage Equivalents.							
SiO_2	47.94	43.80	71.56	70.04	52.72	48.85	41.68
PbO	42.38	38.12	....	....	35.03	....	50.52
K_2O	5.07	8.32	9.01	12.02	5.54	4.30	3.50
Na_2O	4.32	....	8.08	7.44	6.32	4.31	4.00
ZnO	....	3.05	....	....	....	8.91	....
BaO	....	6.47	2.61	....	....	28.57	....
B_2O_3	....	....	....	8.30	....	3.75	....
CaO	....	....	8.02	1.92	....	....	....
Al_2O_3	....	....	....	....	....	1.01	....
As_2O_3	0.29	0.26	0.72	0.28	0.39	0.30	0.30

be used next was heated in another arch. An alternative device for pots which showed a tendency to split open was to pass a chain around them and fasten it.

Under some circumstances it may not be necessary to place the pot in a heated arch to anneal it; instead it is allowed to cool

(with proper protection) on the floor of the furnace-room. Again some glasses may be poured on a casting-table and rolled like plate glass. These matters will be discussed in other papers.

Batch Compositions for Various Types of Glass.

The tables accompanying the article by Zschimmer, previously referred to, contain much valuable information on the compositions of many optical glasses. From these alone it is possible to reproduce almost any optical glass that is made, or we may use them to produce modifications of given types by interpolating between two or more adjacent types. In connection with the work on optical glass that the Geophysical Laboratory has done a great deal of information on the variation of optical properties with composition has been acquired and will soon be published. Thus a quantity of valuable data for producing types of glass of required constants will be available. At the present time the Laboratory is restrained by agreement from publishing any batches which the various plants have themselves developed. This restriction does not apply to batches which the men of the Laboratory introduced, and those which are given herewith in Table 2 fall in this category. Previously given data on temperatures apply to these glasses specifically.

Concluding Remarks.

During the course of this article the writer has taken occasion frequently to emphasize the necessity of attention to details. It may seem that too much stress has been laid upon this and that such matters as following closely the temperature of each pot of glass demand too much skilled labor, and are, after all, unnecessary. This view would be a great mistake. It is surprisingly easy to spoil a pot of glass by a little lack of attention, and the value of one pot will cover a great deal in the matter of wages. In order to get good results in optical glass making it is not possible to conduct operations on a routine that does not take account of variations in conditions which are constantly occurring. One must, instead, treat the process as a laboratory operation carried out on a large scale, and must provide for attention to each pot individually as its requirements demand.

The making of optical glass belongs to a class of operations which American manufacturers have shown a tendency to avoid, apparently preferring to exercise their talents in the direction of turning out great quantities of materials in which each unit may be made to follow the same routine. Products of a more highly specialized kind, such as optical glass, have been obtained from abroad. It seems hardly necessary to emphasize here the lesson which has been taught as to the mistake of a national acceptance of such a policy. It may be well to point out, moreover, that recent events in several branches of industry have demonstrated that there is no lack in this country of men of the necessary scientific and technical equipment to take charge of manufacturing operations of this class and to see that they are properly carried out. It seems that in processes of this kind the same incentives should appeal to manufacturers as in making a good job of any other piece of work in which skill, training, and intelligence are required.

Not all the problems connected with the making of optical glass of a superior quality have been solved. There is still much need of research in order to throw light on certain steps of procedure and remove them from the category of rule-of-thumb operations, and to make more certain the elimination of defects and the production of material that will exactly meet requirements. Some of the subjects for study which may be suggested as promising are a fuller investigation of the function played by arsenic in glass melts and of the amount of volatilization of different ingredients under various conditions, the viscosity of glasses through the temperatures at which stirring is carried on, and the conditions governing the solution of gases in melts. It is to be hoped that some of the manufacturers will turn their attention to having such problems investigated. It is by the inauguration of an enlightened policy of this kind that we in this country may hope to keep in the van in the manufacture of such highly specialized products as optical glass.

CARNEGIE INSTITUTION OF WASHINGTON,
GEOPHYSICAL LABORATORY,
WASHINGTON, D. C.,
February, 1919.

AN IMPROVED METHOD OF OPTICAL GLASS MANUFACTURE.

By George W. Morey.

The usual practice in the manufacture of optical glass consists of the following sequence of furnace operations:[1]

1. **Heating the Pot.**—The pot is carefully pre-heated in a small subsidiary furnace, called a pot arch; from there it is "set" or transferred to the furnace. The pot is usually set at a temperature of about 1050° C, and it must be heated up to the melting temperature of the glass batch, about 1400° for most glasses, before filling. The best practice is to over-burn the pot before commencing the fill.

2. **Filling the Batch.**—The batch, or batch mixed with cullet, is fed into the pot in several installments until the fill is complete. The details of this process differ from plant to plant.

3. **Fining or Planing.**—After the fill is complete the glass is left undisturbed for several hours, primarily to give time for the bubbles to rise to the surface. The temperature during this period is high; in some places it is the practice to use a higher temperature for the fining operation than for the fill.

4. **Intermittent Hand Stir.**—After the fining period is complete it is customary to stir the glass by hand, intermittently; a common schedule is to hand stir for 15 minutes every two hours. This process removes the bubbles of gas adhering to the side and bottom of the pot, and helps to secure uniformity in composition.

5. **Machine Stir.**—After the period of intermittent hand stirring is complete, the glass is stirred continuously, a stirring machine being used. As a rule, soon after putting on the machine, the fire is turned off and the glass allowed to cool, stirring being continued until the pot is removed from the furnace. The

[1] It is assumed that the reader is familiar with standard glass making processes, described in the preceding paper by C. N. Fenner.

operations summarized above take from two to three days in the furnace, the actual time depending on local practice. When, as is usually the case, the empty pots are pre-heated in pot arches, and the finished glass cooled in an appropriate subsidiary apparatus, a melting furnace will yield one pot of glass every two days.

After considerable experience in manufacturing optical glass, certain of the usual operations seemed to be inadequate or illogical, and soon after taking charge of the Optical Glass Plant of the Spencer Lens Company for the War Industries Board, I devised a new schedule, radically different from the above, which may be called the "24-hour" process. Because of its importance in practically doubling the production of optical glass, a basic material in the manufacture of fire control instruments, the details of the process were communicated to the Military Optical Glass and Instrument Section of the War Industries Board, and was communicated by them to the other manufacturers of optical glass.

In the first place, the filling operation required modification. Melting of the batch takes place from the top downward; the upper layer sinters together, then the more easily fusible components trickle down, leaving the upper layers impoverished in the substances usually called "fluxes." This results in the surface becoming high in silica; this was proven by skimmings from both crown and flint batches, which not only showed an actual accumulation of partially dissolved quartz grains, but also had a refractive index lower than that of the rest of the glass.

The fluxes, especially lead, tend to settle to the bottom; this is proven by the dark layer always brought up when hand stirring is begun; by tests made by plunging a long iron rod into the glass and quickly withdrawing it; and, by the examination of partially melted batches which have been removed from the furnace because of leaks, and broken after cooling. In the latter case, the preponderance of silica mentioned above has also been observed.

This initial inhomogeneity, it is true, is removed by the subsequent stirring operation, and this probably accounts for its harmful effects having been overlooked. One of these harmful effects,

especially in flint glasses, is due to the fact that lead-rich mixtures (for example, the extra dense flints) are extremely corrosive on the pots. By the older process this lead-rich layer is allowed to lie on the bottom of the pot throughout the filling and the fining periods, both of which periods are of some hours' duration and of extremely high temperature. This necessarily results in greatly increased pot corrosion. In addition, the impoverishment of the upper layers in fluxes increases the time required for complete solution of the batch ingredients.

The obvious remedy is to stir during the fill.[1] This is not feasible until the pot is a little over half full, because the stirring rod cannot be floated before this, but as soon as feasible, it should be begun, and the melt should be stirred each time new batch is added. Making such a stir during the fill should diminish pot corrosion, give a better quality glass, glass freer from color, striae and stones, and should hasten the solution of the batch and thereby shorten the melting process.

After the fill is completed the glass must be freed from bubbles of gas arising from the decomposition of carbonates and nitrates in the batch, and from the water in the batch ingredients. In some cases these volatile components comprise one-fifth of the weight of batch filled. By the old process the bubbles are mainly removed during the fining operation, the glass being kept hot and undisturbed for some time to allow the bubbles to rise to the surface. The intermittent hand stir that follows, supplements the fining period by removing the layer of bubbles which adheres to the pot-walls, and also tends to secure uniformity in composition throughout the melt.

That seemed an illogical way to secure the desired result. In the first place, common experience is that bubbles in other liquids are more rapidly removed by stirring than by quiescence. It seemed reasonable to suppose that in a pot of glass also the bubbles will be more rapidly removed by stirring. Moreover, in the usual process the glass is not homogeneous in composition

[1] Since presenting this paper I have heard that at one time stirring during the fill was tried at the Charleroi plant of the Pittsburgh Plate Glass Co.; others doubtless have made the same attempt.

until after the fining period; the upper layer is deficient in fluxes, and hence melts less rapidly than the mass of the glass. The margin in composition between an unworkably viscous glass and a workable glass is a narrow one; the stirring should prevent the upper portion being deficient in fluxes and hence too viscous to permit the free passage of bubbles. It seemed a reasonable supposition, therefore, that two of the operations to which optical glass is usually subjected could be dispensed with, namely, the long fining period and the period of intermittent hand stirring. In other words, it seemed that better results could be obtained by putting on the stirring-machine immediately after the fill, and stirring continuously until the glass was free from bubbles. With this modification could well be combined a hand stir during the fill, as mentioned before.

The best test of the above reasoning is the results. The new schedule was tried out on a melt of flint glass having an index of 1.617. The melt was run at the usual temperature for this glass, 1390° C. Fills were made at 2-hour intervals, the first fill being about $^1/_3$ of the total batch, and on each subsequent fill the pot was heaped up with batch. As soon as possible a hand stir was made; ten hours after the first fill the stirring-machine was put on; at this time there was still undissolved batch, not all quartz. The stirring-machine was run at a good speed, both with a circular and a vertical motion. After six (6) hours the glass seemed free from bubbles; the fire was accordingly turned off and the pot cooled and removed as usual. The entire process, from the time the pot was set until the melt was out of the furnace and another pot set, was 24 hours. When the glass was examined it proved to be of the best quality: wholly free from bubbles, of greatly improved color, and also freer from striae than usual.

The details of the process were subsequently modified, and special schedules were worked out for the different types of glass. Following is a sample schedule, being that for a flint, having $n_D = 1.617$, $\nu = 36.5$. The pot used is 26 inches high and 28 inches in diameter, inside dimensions. The time of filling in the cullet is taken as zero hour.

SCHEDULE FOR MF_2 GLASS.

Time: hours.	Run at 1390° C.
0:00	Add cullet
1:00	Fill pot $^3/_4$ full of batch
2:30	Fill pot with batch
4:00	Hand stir; fill pot with batch
5:30	Hand stir; fill pot with batch
7:00	Hand stir; fill pot with batch
7:30	Stirring-machine on
15:00	Gas off.

When cooled to the proper temperature the pot of glass is removed from the furnace and slowly cooled in a pot arch. A new pot is set into the furnace and given a preliminary burning, so that in 24 hours all is ready for another melt.

It may be well to emphasize one point of difference between the longer process and the 24-hour process. In the former the melt, often with an unduly corrosive layer on the bottom, remained in contact with the hot pot for from 20–30 hours from the time the last fill was made until the gas was turned off; in the 24-hour process the corresponding period of maximum corrosive action is 5 or 6 hours. As the greater part of the contamination of glass by iron, with our present raw materials, comes from the pot, the superiority of the newer process is obvious. Better color results from smaller pot contamination, as does also a greater freedom from striae, less trouble from stones, and less pot breakage.

The first experimental pot of glass made by the 24-hour process proved a complete success. Since that time some 350 pots of glass have been made, and all by the shorter schedule. They comprise practically all types of glass; flints, from an extra dense flint with refractive index of 1.76 to an extra light flint with index of 1.55; soft crowns and ordinary crowns of three different types; several types of borosilicate crown; several barium crowns, baryta flint with index 1.56 to a dense baryta flint, index 1.62. Without exception the new process has produced a better glass than the old, with a doubling of production and correspondingly lower cost.

SPENCER LENS GLASS PLANT, HAMBURG, N. Y.
CARNEGIE INSTITUTION OF WASHINGTON,
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February 12, 1919.

A COMPARISON OF AMERICAN CHINA CLAYS AS PORCELAIN INGREDIENTS.

By Arthur S. Watts.

As a result of a study of the numerous attempts during the war to make a substitution of American clays not only for foreign clays but also for other American china clays, we are convinced that very few users of American china clays or kaolins are aware of the serious results which may develop from the indiscriminate substitution of one clay for another—even though the sources of supply may be separated by but a few miles and the mode of occurrence be apparently the same. To the average user of china clay, the terms Delaware kaolin, North Carolina kaolin, South Carolina kaolin and Georgia kaolin are ones which condemn or recommend a clay—depending upon the previous experience of the consumer with materials sold under those names. The Florida kaolin has fortunately established its identity more definitely and most users of white clays are acquainted with its merits and limitations.

The Bureau of Mines will publish, in the near future, data on the clay from each mine being operated in the Atlantic Coast States during 1918, and from these data an opportunity for a careful comparison can be secured.

The samples tested in the present investigation were taken from commercial stock—the selection of the sources of the clays being controlled chiefly through convenience. No attempt was made to obtain the best product from any one district. The clays selected were as follows:

Sample O—M. W. M. English China clay. Moore and Munger, 29 Broadway, New York.

Sample A—Delaware kaolin. Newark China Clay Co., P. O. Box 220, Wilmington, Del. (Shipped from Thompson, Del.)

Sample B—North Carolina kaolin. Hand Clay Co., Canton, N. C. (Shipped from Woodrow, Haywood County, N. C.)

Sample C—North Carolina kaolin. Harris Clay Co., Dillsboro, N. C. (Shipped from Dillsboro, Jackson County, N. C.)

TABLE I

	Bodies.	Per cent water of plasticity.	Per cent drying shrinkage.	Per cent total shrinkage		Per cent absorption.		Per cent warpage.		Per cent translucency.		Color.	
				Cone 7.	Cone 10.	Cone 7.	Cone 10.	Cone 7.	Cone 10.	Cone 7.	Cone 10.	Cone 7.	Cone 10
O.	Eng. china clay body.....	26.0	5.0	13.4	16.7	1.4	0.0	0.14	0.37	7	1	1	2
A.	Del. kaolin body.....	25.8	4.0	11.0	13.8	1.9	0.0	0.25	0.32	6	2	9	5
B.	N. C. kaolin body.....	26.1	3.2	10.0	11.7	4.0	0.2	0.16	0.18	8	6	8	4
C.	N. C. kaolin body.....	19.2	2.8	10.0	12.0	2.7	0.0	0.27	0.37	3	3	3	1
D.	S. C. kaolin body.....	23.4	2.8	11.6	11.8	3.6	0.3	0.23	0.29	4	7	7	7
E.	S. C. kaolin body.....	25.8	2.0	12.0	12.0	2.7	0.0	0.30	0.33	1	5	6	9
F.	S. C. kaolin body.....	28.8	2.0	12.2	12.7	3.5	0.2	0.17	0.18	5	4	5	3
G.	Ga. kaolin body.....	23.9	3.6	12.2	13.4	4.1	0.4	0.19	0.40	2	3	4	8
H.	Ga. kaolin body.....	24.1	3.1	9.0	11.5	4.0	0.0	0.19	0.15	9	9	2	10
I.	Ga. kaolin body.....	24.8	3.5	10.6	13.5	4.4	0.7	0.15	0.14	10	10	10	6

Sample D—South Carolina kaolin. Interstate Clay Co., Sumter, S. C. (Shipped from James Crossing, Sumter County, S. C.)

Sample E—South Carolina kaolin. McNamee Kaolin Co., Cumberland Bldg., Broadway at 54th St., New York. (Shipped from Bath, Aiken County, S. C.)

Sample F—South Carolina kaolin. Edisto Kaolin Co., Bridgeport Nat'l Bank Bldg., Bridgeport, Conn. (Shipped from Samaria, Aiken County, S. C.)

Sample G—Georgia kaolin. Edgar Bros. Co., Metuchen, N. J. (Shipped from McIntyre, Wilkinson County, Ga.)

Sample H—Georgia kaolin. Georgia Kaolin Co., Macon, Ga. (Shipped from Dry Branch, Twiggs County, Ga.)

Sample I—Georgia kaolin. Golding Sons Co., Butler, Ga. (Shipped from Butler, Taylor County, Ga.)

A body having the following composition was chosen for testing the properties of each clay:

	Per cent.
Feldspar (Canadian)	20
Whiting	2
Tenn. ball clay No. 7	10
Florida kaolin (Edgar Plastic Kaolin Co.)	10
Clay being tested	25
Flint	33

These bodies were wet-ground for four hours in ball mills, transferred to plaster absorption bowls lined with cambric to prevent contamination, and were then thoroughly wedged and molded into the following shapes:

Wedges, 3″ long, 1″ wide, tapering from $^3/_4$″ to 0″.

Warpage trials, 7″ long, 1″ wide, $^1/_2$″ thick.

Cups, approximately $3^1/_2$″ diameter by 2″ high (jiggered).

The warpage trials were placed on wedges in firing, with 5″ span.

Trials from each body were fired in two burns to cones 7 and 10, the data secured from the burned pieces being given in the table on the preceding page.

Conclusions.

A study of the foregoing data indicates that the variation in the physical properties of the clays tested is worthy of serious consideration. The water content for the best working plasticity is fairly constant, 23.4 per cent to 26.1 per cent, except in the

cases of the Harris North Carolina kaolin which required only 19.2 per cent and the Edisto South Carolina kaolin which required 28.8 per cent water.

The drying shrinkage was greatest in the body containing English china clay, followed by the Delaware, Georgia, North Carolina and South Carolina kaolins, respectively.

The American clay bodies, when fired to cone 7 and 10, had a lower total shrinkage than the English clay body in every case.

The rates of vitrification of the different clays, as evidenced by the absorptions of the different bodies, were somewhat surprising. The bodies containing Georgia kaolin were more porous than any of the others when fired to cone 7, with the South Carolina kaolin bodies next, followed by the North Carolina, the Delaware, and the English china clay body, which was the most vitreous at cone 7. The same order of porosity was also noted in the pieces fired to cone 10.

The warpage behavior of the bodies is interesting, since the English china clay body, although the most vitreous at cone 7, shows the least warpage when fired to this cone. At cone 10, however, it had about the same warpage as the other bodies, there being only three exceptions, B, the Hand North Carolina kaolin, F, the Edisto, South Carolina kaolin and H, and I, the Georgia Kaolin Co. bodies which had exceptionally low warpage at cone 10.

Probably the most important consideration in studying these bodies are the translucency and color. It will be noted that the bodies showing the highest translucency at cone 7 do not have the highest translucency at cone 10. In but one case does the relative translucency of a body remain the same at both cones. We judge from this that the temperature at which a body is to be fired is of vital importance in the selection of the kaolin to be used. At cone 10, which is about the average maturing cone for whiteware bodies, the English china clay showed the best translucency, then followed the Delaware kaolin, a North Carolina kaolin, a South Carolina kaolin and lastly the Georgia kaolins.

In considering the color, which is of even more importance than translucency, the results at cone 10 indicate the following order of excellence: North Carolina, English, South Carolina,

North Carolina, Delaware, Georgia, South Carolina, Georgia, South Carolina, and Georgia kaolins. The difference in color, although small, is worthy of careful consideration and, while the other properties remain reasonably constant for a limited area, the color and translucency vary widely within limited areas and only by careful test and selection can the best results be obtained. The color classification as given in the table is the result of grading by only two persons, and in the absence of any standard method of test is, of course, open to the fault of the personal factor.

Department of Ceramic Engineering,
Ohio State University,
Columbus, Ohio.

AMERICAN CERAMIC SOCIETY.

Acquisition of New Members during February, 1919.

Associate.

Ahrens, Robt. S., California Metal Enam. Co., Los Angeles, Cal.
Agge, Franklin, Republic Metalware Co., Buffalo, N. Y.
Arensberg, C. C., McCullough-Dalzell Crucible Co., Pittsburgh, Pa.
Barnes, T. R., Barnes Mfg. Co., Mansfield, Ohio.
Blair, J. A., Kushequa Brick Co., Kushequa, Pa.
Buckley, J. L., Phila. Drying Machine Co., Philadelphia, Pa.
Chaffin, Edwin G., Norton Company, Worcester, Mass.
Collin, Louis, Alfred, N. Y.
Coxon, J. B., Standard Sanitary Mfg. Co., Kokomo, Ind.
Crawford, George E., Alfred, N. Y.
Crume, Wm. H., Crume Brick Co., Dayton, Ohio.
Czerny, Leonard, Mosaic Tile Co., Zanesville, Ohio.
Dains, I. F., Western Stoneware Co., Monmouth, Ill.
DeWitt, Bert G., Belmont S. & E. Co., New Philadelphia, Ohio.
Dimcombe, Geo. H., Jr., Evens & Howard Fire Brick Co., St. Louis, Mo.
Edwards, W. L., Wheeling Sanitary Mfg. Co., Tiltonville, Ohio.
Enright, Bernard, Allentown, Pa.
Fisher, E. E., Federal Glass Co., Columbus, Ohio.
Foskett, John J., Foskett Co., Inc., Port Jervis, N. Y.
Foster, Harry D., Mosaic Tile Co., Zanesville, Ohio.
Goodwin, Herbert, Salem China Co., East Liverpool, Ohio.
Hagar, Donald, Alfred, N. Y.
Harvey, Ives L., Bellefonte, Pa.
Henshaw, S. B., Libbey-Owens Glass Co., Charleston, W. Va.
Heuisler, Philip I., Maryland Glass Corp., Baltimore, Md.
Hinrichs, Carl G., Hinrichs Laboratories, St. Louis, Mo.
Hostetter, J. C., Geophysical Laboratory, Washington, D. C.
Hunt, Marsden H., Univ. of Illinois, Urbana, Illinois.
Jenks, H. P., Hook Patent Kiln Co., Columbus, Ohio.
Jewett, Richmond, Jewett Refrigerator Co., Lackawanna, N. Y.
Kirk, Herbert S., Universal Sanitary Mfg. Co., New Castle, Pa.
Lapp, G. W., Lapp Insulator Co., LeRoy, N. Y.
Limberg, Frank, Limberg Enameling Works, Cincinnati, Ohio.
Lin, S. Y., Ohio State University, Columbus, Ohio.
Lindsay, G. W., Denver Fire Clay Co., Denver, Ohio.
Mahoney, W. T., Cahill Iron Works, Chattanooga, Tenn.
Memory, N. H., Isbell-Porter Co., Newark, N. J.

Palmer, Chas. S., Mellon Institute, Pittsburgh, Pa.
Porter, J. Edward, Box 785, Syracuse, N. Y.
Rentschler, M. J., J. H. R. Products Co., Willoughby, Ohio.
Roddewig, Ed., Iowa State College, Ames, Iowa.
Sauereisen, C. Fred, Empire China Works, Brooklyn, N. Y.
Schurtz, D. D., Frink Laboratories, Lancaster, Ohio.
Shively, R. R., Monongah Glass Co., Fairmont, W. Va.
Smoot, C. E., 1900 Santa Fé Ave., Los Angeles, Cal.
Sosman, Robert B., Geophysical Laboratory, Washington, D. C.
Stowe, G. T., Lock Haven Fire Brick Co., Lock Haven, Pa.
Vollrath, W. J., Porcelain Enameling Association, Sheboygan, Wis.
Wainford, Richard H., Trenton Flint & Spar Co., Trenton, N. J.
Williams, R. G., Stanley Insulating Co., Great Barrington, Mass.
Williams, W. S., Bureau of Standards, Pittsburgh, Pa.

Foreign.

Cole, L. Heber, Mines Branch, Dept. of Mines, Ottawa, Ont., Canada.
Scott, Alex., Central School of Science & Technology, Stoke-on-Trent, Eng.
Skidmore, George R. J., Geo. Davidson & Co. Glass Works, Gateshead-on-Tyne, England.

Contributing.

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U. S. Glass Co., Pittsburgh, Pa.
L. J. Houze Convex Glass Co., Point Marion, Pa.
Macbeth-Evans Glass Co., Pittsburgh, Pa.
Phoenix Glass Co., Pittsburgh, Pa.
Trenton Flint & Spar Co., Trenton, N. J.
Western Stoneware Co., Monmouth, Ill.

LOCAL SECTIONS.

Chicago Section.

The fifth meeting of the Chicago Section of the American Ceramic Society was held at the City Club, Chicago, January 11, 1919. In the absence of President W. D. Gates, Vice-President I. E. Hardy presided. The minutes of the previous meeting were dispensed with and the election of officers for the ensuing year was taken up with the following result:

Chairman, I. E. HARDY, Tiffany Enameled Brick Co., Momence, Ill.

Vice-Chairman, A. F. HOTTINGER, Northwestern Terra Cotta Co., 2525 Claybourn Ave., Chicago, Ill.

Secretary and Treasurer, H. T. BELLAMY, Hawthorne Works, Western Electric Co., Inc., Chicago, Ill.

Councilor, C. W. PARMELEE, University of Illinois, Urbana, Ill.

Chairman of Program Committee, R. R. DANIELSON, Benjamin Electric Manufacturing Co., Des Plaines, Ill.

Chairman of Membership Committee, B. S. RADCLIFFE, Midland Terra Cotta Co., Lumber Exchange, Chicago, Ill.

After the election of officers, the three following very interesting papers were presented and discussed:

"*Production*," G. G. LAWSON, Northwestern Terra Cotta Co., 2525 Claybourn Ave., Chicago, Ill.

"*The Use of Powdered Fuel*," F. L. STEINHOFF, "Brick and Clay Record," 610 Federal St., Chicago.

"*Clay Mines in Tennessee and Kentucky*," Prof. C. W. PARMELEE, University of Illinois, Urbana, Ill.

ADJOURNED.

H. T. BELLAMY,
Secretary.

ACTIVITIES OF THE SOCIETY

Proceedings of the Board of Trustees at Pittsburgh, February 2-5, 1919.

A meeting was held in the Secretary's room at the Fort Pitt Hotel on Sunday evening, February 2nd, at 7.30. There were present, Homer F. Staley, President, A. F. Greaves-Walker, Vice-President, R. K. Hursh, Treasurer, E. T. Montgomery, R. D. Landrum, G. H. Brown, Trustees, Chas. F. Binns, Secretary, and Norah W. Binns, Assistant Secretary.

The Secretary read a draft of the report of the Board to be presented to the Society. After discussion and some minor alterations this was by vote adopted.

It was voted that the proceedings of the Board during the year, including motions and resolutions passed, be published in the Year Book together with the dates at which they were made, and that current motions in their final and complete form be transmitted to the Editor monthly by the Secretary for publication in the Journal.

It was voted to complete thirty sets, if possible, of the Transactions, bound in cloth.

It was voted that no ballots for the election of incoming officers be received later than 10 A.M. on Tuesday, February 4th.

In response to an inquiry by the Secretary as to the date upon which membership should be considered to have lapsed, it was voted to send the Journal for January, February and March to all members irrespective of payment of dues.

It was voted that in the opinion of the Board the Society should continue to be represented at the Exposition of Chemical Industries.

Letters were read which had passed between Lt.-Col. Orton and Dr. J. W. Mellor of the English Ceramic Society with reference to a possible joint meeting of the two Societies in this country in the summer of 1920. It was voted that the Secretary issue a formal invitation to the English Ceramic Society to attend a joint meeting at that time, and that a committee of three, with power to add to their number, be appointed to make the necessary arrangements.

A request was presented from Mr. F. H. Rhead for the formation of a Professional Division on Ceramic Decorative Processes. It was voted that the Secretary advise Mr. Rhead that if ten members apply for the organization of such a Division an authorization will be given.

Several modification of the Rules were suggested and it was voted that these be referred to the Committee on Rules for consideration and, if approved, for presentation to the Society before the close of the Convention.

A list of names which had been presented for elevation to Active Membership was passed in review and some tentative changes were made.

The Board met at the same place on Monday evening, February 3rd, at 9 o'clock. All the members were present, together with Mr. R. H. Minton, Vice-President elect, and Mr. M. F. Beecher, Trustee elect.

The names of 102 resident Associates and 13 foreign Associates were passed for election to Active Membership.

It was voted to discontinue the employment of a stenographer to report discussions and to engage a local stenographer as occasion might arise for the report of the business meeting of the Society.

It was voted that the Secretary might at his discretion consider, after a reasonable lapse of time, that a motion before the Board in correspondence is decided if a minimum of three votes shall have been received and recorded.

It was voted that the Treasurer furnish a satisfactory bond in the sum of $5000 and that the Secretary's bond of $2000 be renewed.

It was voted to remove the names of all German members from the rolls, on the ground that their dues have not been paid.

A meeting of the newly-elected Board was held in the Assembly Room on February 5th at 6 o'clock. All the members were present.

It was voted that a Professional Division on Wall and Floor Tile be authorized and that the President appoint a chairman.

It was voted that the resolution which empowered the Secretary to purchase copies of Volume XIX at $5 each be amended to read "at the market price."

It was voted that one copy of the "Directory of Dealers in Raw Ceramic Materials" be sent to each Member and Associate of the Society, except to those who have already purchased them, and that the money paid for such purchases be refunded.

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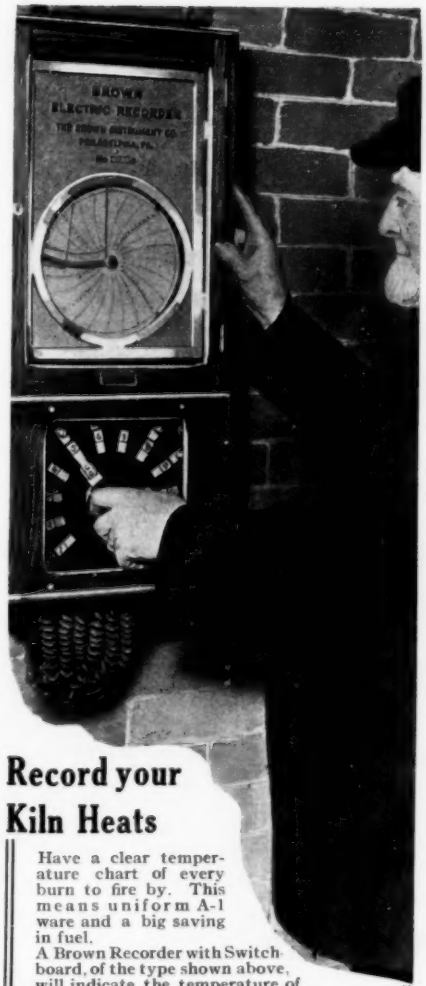

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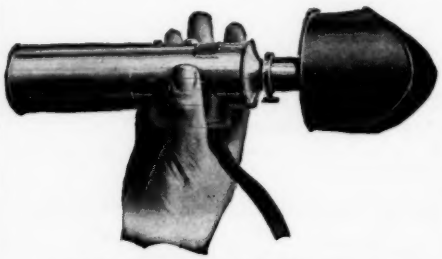

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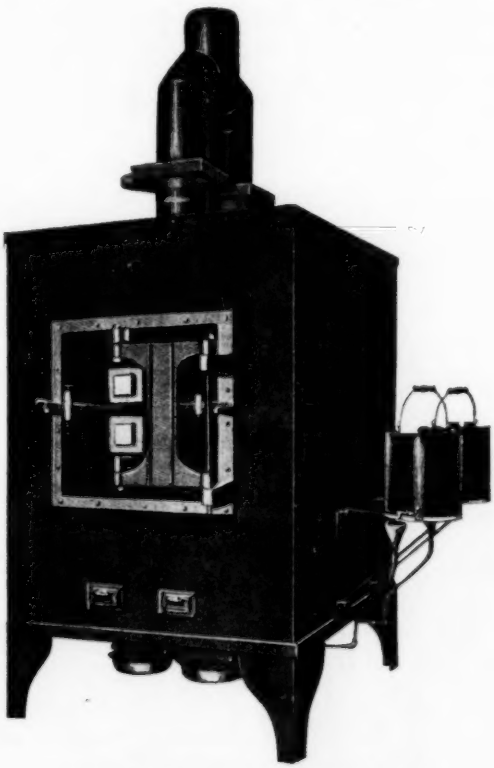

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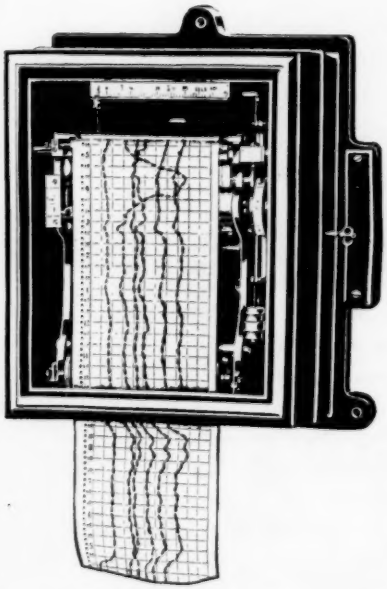

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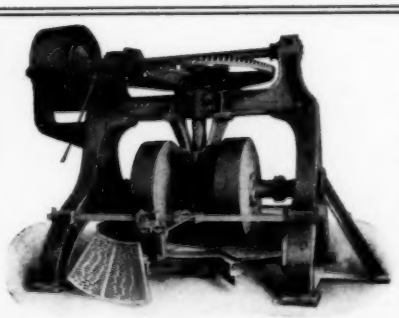

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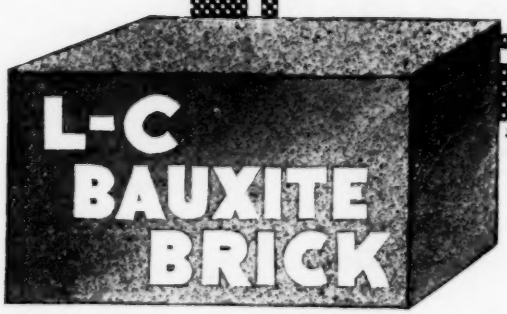

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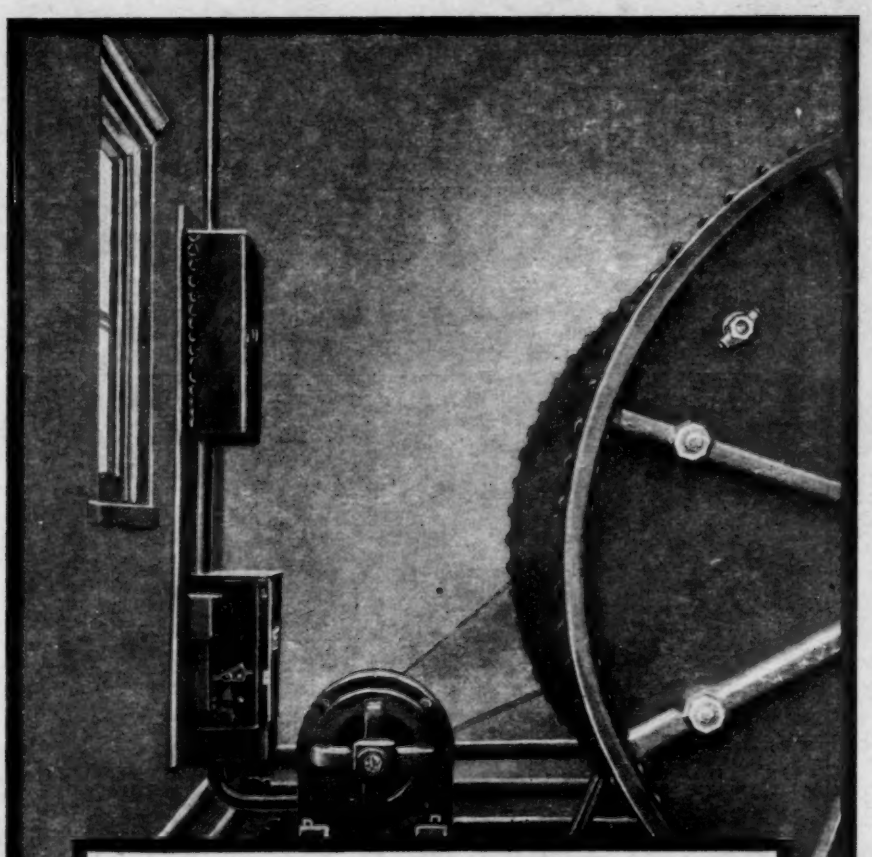

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